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МАММАДОВА АЙНУР ТЕЙЮБ

Physical and Mathematical Sciences

УДК 372.853

МЕКТЕПТЕ ФИЗИКАНЫ ОҚЫТУДА ОҚУШЫЛАРДЫҢ ФУНКЦИОНАЛДЫҚ САУАТТЫЛЫҒЫН ДАМУ

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I.Жансүгіров атындағы Жетісу университетінің магистрі

Аннотация: Бұл мақалада жалпы білім беретін мектептердегі білім беру жүйесінің басты мақсаттарының бірі – функционалдық сауатты тұлғаны қалыптастыру екені көзделген. Мақалада мұндай тұлға зияткерлік тұрғыдан дамыған, рухани бай, дене жағынан жетілген және қоғамда өз орнын таба алатын азамат ретінде сипатталатыны негізделген.

Кілттік сөздер: функционалдық, АКТ, сауаттылық, қоғам, зерттеу, инновация, белсенділік, шығармашылық, кәсіби, шешім.

КІРІСПЕ

Функционалдық сауаттылық – қазіргі қоғамдағы жеке тұлғаның табысты өмір сүруінің маңызды көрсеткіштерінің бірі. Ол адамның сыртқы ортамен тиімді қарым-қатынас орната алу қабілетін, өзгермелі жағдайларға бейімделу деңгейін және әлеуметтік ортада белсенді әрекет ету мүмкіндігін сипаттайды. Яғни, функционалдық сауаттылық тек білімді меңгеру ғана емес, сол білімді өмірлік жағдайларда дұрыс қолдана білу дағдыларын қамтиды.

Ғылыми тұрғыдан алғанда, функционалдық сауаттылық тұлғаның белгілі бір мәдени және әлеуметтік ортада өмір сүруі үшін қажетті білім, білік және дағдылар жүйесі болып табылады. Бұл қасиеттер адамның қоғаммен өзара әрекеттесуін қамтамасыз етіп, оның әлеуметтік рөлін тиімді атқаруына ықпал етеді. Сонымен қатар, функционалдық сауаттылық адамның өз бетінше шешім қабылдауына, сыни ойлау қабілетін дамытуына және ақпаратты дұрыс талдап, қолдануына мүмкіндік береді[1].

Кең мағынада функционалдық сауаттылық тек жеке тұлғаның қасиеті ғана емес, ол – қоғамның, ұлттың және жалпы мемлекеттің даму деңгейін айқындайтын маңызды көрсеткіш. Себебі функционалдық тұрғыдан сауатты азаматтар қоғамның экономикалық, мәдени және әлеуметтік дамуына белсенді үлес қосады. Осы тұрғыдан алғанда, функционалдық сауаттылық – адам дамуының негізгі тетіктерінің бірі.

Функционалдық сауаттылық ұғымы адамдардың әлеуметтік, мәдени, саяси және экономикалық өмірге белсенді араласуын білдіреді. Қазіргі жаһандану дәуірінде бұл ұғымның маңызы ерекше артып отыр. Себебі заманауи қоғамда әрбір адам өз білімін үнемі жетілдіріп, жаңа ақпараттарды игеріп, өзгерістерге бейімделе алуы қажет. Бұл талаптар адамның жасына немесе мамандығына қарамастан, өмір бойы білім алуға деген қажеттілікті қалыптастырады.

Жалпы білім беретін мектептердегі білім беру жүйесінің басты мақсаттарының бірі – функционалдық сауатты тұлғаны қалыптастыру. Мұндай тұлға зияткерлік тұрғыдан дамыған, рухани бай, дене жағынан жетілген және қоғамда өз орнын таба алатын азамат ретінде

сипатталады. Сонымен қатар, ол жаһандық ортада бәсекеге қабілетті болып, түрлі әлеуметтік жағдайларға оңай бейімделе алады.

Қазіргі жаһандану жағдайында білім беру жүйесіне қойылатын талаптар түбегейлі өзгеруде. Қоғамның дамуы тек білімді ғана емес, сонымен қатар сол білімді өмірде тиімді қолдана алатын, дербес шешім қабылдайтын, шығармашылық тұрғыда ойлайтын тұлғаны қажет етеді. Осыған байланысты білім беру мазмұны да функционалдық сауаттылықты дамытуға бағытталуда.

Функционалдық сауаттылық – тұлғаның әлеуметтік ортада еркін әрекет етуіне, түрлі өмірлік жағдайларда дұрыс шешім қабылдауына мүмкіндік беретін негізгі қасиеттердің жиынтығы. Мұндай тұлғаны қалыптастыру үшін білім алушылардың бойында бірқатар маңызды сапаларды дамыту қажет. Зерттеу жұмысының мақсаты – тұлғаның функционалдық сапаларын қалыптастырудың мәнін ашу және олардың білім беру үдерісіндегі рөлін анықтау.

Міндеттері: тұлғаның негізгі сапаларын талдау; әр сапаның маңыздылығын сипаттау; білім беру процесінде дамыту жолдарын қарастыру. Тұлғаның дамуы – күрделі әрі көпқырлы процесс. Қазіргі педагогикада тұлғаның қалыптасуы тек білім алумен шектелмей, оның өмірлік дағдыларды игеруімен тығыз байланысты қарастырылады [2].

Функционалдық сапалар – бұл адамның өмірде табысты әрекет етуіне мүмкіндік беретін жеке қасиеттер жиынтығы. Бұл сапалар тұлғаның: әлеуметтік бейімделуін; кәсіби бағыттылығын; өзін-өзі дамыту қабілетін қамтамасыз етеді. Қазіргі білім беру жүйесі оқушыны тек ақпаратты қабылдаушы емес, оны талдаушы, қолданушы және жаңалық жасаушы тұлға ретінде қалыптастыруды көздейді.

Белсенділік – тұлғаның оқу үдерісіне деген қызығушылығы мен қатысу деңгейін білдіреді. Белсенді оқушы: өздігінен ізденеді; сұрақтар қояды; тапсырмаларды шығармашылықпен орындайды. Белсенділік білім сапасын арттырып, тұлғаның дербестігін қалыптастырады.

Шығармашылық ойлау – жаңа идеялар ұсыну, мәселені стандартты емес жолмен шешу қабілеті. Бұл сапа: инновациялық ойлауды дамытады; ғылыми зерттеу дағдыларын қалыптастырады; тұлғаның интеллектуалдық деңгейін арттырады.

Шешім қабылдау – түрлі жағдайларды саралап, ең тиімді нұсқаны таңдай білу қабілеті. Бұл сапа: логикалық ойлаумен; жауапкершілікпен; тәжірибемен байланысты. Оқушы өмірлік мәселелерді шешуде дербестікке үйренеді.

Кәсіпті дұрыс таңдау – тұлғаның болашақ өміріндегі табыстың негізі. Бұл үшін: қызығушылықтарды анықтау; қабілеттерді бағалау; еңбек нарығын ескеру маңызды. Кәсіби бағдар беру – білім беру жүйесінің маңызды бөлігі.

Бұл сапа тұлғаның үздіксіз дамуға ұмтылысын білдіреді. Қазіргі қоғамда: білім тез ескіреді; жаңа дағдылар қажет болады; өзін-өзі дамыту маңызды. Өмір бойы оқу – табысты тұлғаның негізгі белгісі.

Функционалдық сапаларды қалыптастыру жолдары. Бұл сапаларды дамыту үшін келесі әдістер тиімді:

- интерактивті оқыту әдістері (пікірталас, топтық жұмыс, жобалық әдіс),
- ақпараттық-коммуникациялық технологияларды қолдану (онлайн платформалар, цифрлық ресурстар),
- практикалық тапсырмалар мен өмірлік жағдайларды модельдеу,
- зерттеу және жобалық жұмыстар, - кәсіби бағдар беру жұмыстары. Бұл тәсілдер оқушының белсенділігін арттырып, оның тұлғалық дамуына ықпал етеді [3].

Қорытынды

Қорытындылай келе, тұлғаның функционалдық сапалары – қазіргі білім беру жүйесінің негізгі бағыттарының бірі болып табылады. Белсенділік, шығармашылық ойлау, шешім қабылдау, кәсіби бағдар және өмір бойы білім алу қабілеті тұлғаның жан-жақты дамуын қамтамасыз етеді. Осы сапаларды қалыптастыру арқылы ғана білім алушыны өмірге бейімделген, бәсекеге қабілетті тұлға ретінде тәрбиелеуге болады. Сондықтан білім беру үдерісінде бұл бағытқа ерекше назар аудару қажет. Қорытындылай келе, функционалдық сауаттылық – қазіргі білім беру жүйесінің негізгі басымдықтарының бірі. Ол жеке тұлғаның жан-жақты дамуын қамтамасыз етіп қана қоймай, қоғамның тұрақты дамуына негіз болады.

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ИННОВАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАРДЫ ҚОЛДАНУ АРҚЫЛЫ ФИЗИКАНЫ ОҚЫТУДЫҢ САПАСЫН АРТТЫРУ

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Аннотация: Бұл мақалада мектептегі оқушыларға инновация ұғымын дұрыс түсіну үшін оны «жаңалық» ұғымымен салыстыра қарастыру маңызды екені және жаңалық – бұл ғылыми зерттеулердің, тәжірибелік жұмыстардың немесе шығармашылық ізденістердің нәтижесінде алынған жаңа өнім, әдіс немесе идея. Ал инновация осы жаңалықтың нақты практикада қолданылып, тиімділік беруі.

Кілттік сөздер: модель, АКТ, виртуалды, дағдылар, зерттеу, инновация.

КІРІСПЕ

Инновация – бұл тек жаңа идеяның пайда болуы ғана емес, оны тәжірибеге енгізіп, нақты нәтиже алуға бағытталған күрделі әрі көпсатылы үрдіс. Ол ғылыми-техникалық шешімдердің, жаңа әдістердің, технологиялардың немесе ұйымдастырушылық тәсілдердің өмірде қолданылып, қоғамға пайда әкелуін қамтиды. Яғни инновация – идеядан бастап оны іске асыруға дейінгі толық цикл. Инновация ұғымын дұрыс түсіну үшін оны «жаңалық» ұғымымен салыстыра қарастыру маңызды. Жаңалық – бұл ғылыми зерттеулердің, тәжірибелік жұмыстардың немесе шығармашылық ізденістердің нәтижесінде алынған жаңа өнім, әдіс немесе идея. Ал инновация осы жаңалықтың нақты практикада қолданылып, тиімділік беруі [1].

Мысалы:

- физикада жаңа заңның ашылуы – бұл жаңалық. Ал сол заң негізінде жаңа құрылғы жасап, өндірісте қолдану – инновация;
- білім беру саласында жаңа оқыту әдісін ойлап табу – жаңалық, ал оны мектептерде енгізіп, оқушылардың білім сапасын арттыру – инновация;
- күн энергиясын пайдалану технологиясының жасалуы – жаңалық, ал күн панельдерін жаппай орнатып, электр энергиясын өндіру – инновация;

Жаңалық әртүрлі формада көрініс табуы мүмкін. Оларға мыналар жатады: ғылыми ашылулар, патенттер, жаңа технологиялар, өндірістік процестердің жетілдірілген үлгілері, ноу-хау, әдістемелік нұсқаулықтар, стандарттар, маркетингтік зерттеулер нәтижелері және т.б. Алайда жаңалықтың өзі автоматты түрде инновацияға айналмайды. Ол үшін оны өндіріске енгізу, тарату және қолдану қажет. Инновациялық процестің маңызды кезеңдерінің бірі – инновациялық диффузия, яғни жаңалықтың қоғамда кең таралуы. Мысалы, бастапқыда тек жекелеген мектептерде қолданылған цифрлық білім беру платформалары кейін бүкіл ел бойынша енгізіліп, жалпы білім беру жүйесінің ажырамас бөлігіне айналды.

Негізгі бөлім

Сондай-ақ, кез келген жаңалықты енгізу үшін алдын ала маркетингтік және әлеуметтік зерттеулер жүргізу маңызды. Бұл оның қажеттілігін, тиімділігін және қолдану мүмкіндігін

анықтауға көмектеседі. Себебі кейбір жаңалықтар ғылыми тұрғыдан құнды болғанымен, практикада сұранысқа ие болмауы мүмкін.

Қазіргі жаһандану және цифрландыру жағдайында қоғамның барлық салалары қарқынды дамуда. Әсіресе білім беру, ғылым және өндіріс салаларында жаңа технологиялар мен әдістерді енгізу ерекше маңызға ие болып отыр. Осы тұрғыдан алғанда, «инновация» ұғымы заманауи дамудың негізгі қозғаушы күштерінің бірі болып табылады. Инновация тек жаңа идеялармен шектелмей, оларды тәжірибеде тиімді қолдануды қамтитын кешенді процесс ретінде қарастырылады.

Инновация – жаңа идеяларды, ғылыми жетістіктерді, технологияларды немесе басқару тәсілдерін тәжірибеге енгізу арқылы нақты нәтижеге қол жеткізу процесі. Ол тек жаңалық ашумен ғана шектелмейді, сонымен қатар сол жаңалықты іске асыру, тарату және қоғам игілігіне пайдалану кезеңдерін қамтиды. Инновацияның басты мақсаты – экономикалық, әлеуметтік, ғылыми-техникалық немесе экологиялық тиімділікке қол жеткізу. Мысалы, өндірісте жаңа технология енгізу арқылы өнім сапасын арттыру немесе шығынды азайту – инновацияның нақты көрінісі. Көп жағдайда «жаңалық» пен «инновация» ұғымдары бірдей мағынада қолданылғанымен, олардың арасында айқын айырмашылық бар [2].

Жаңалық – ғылыми зерттеулер мен тәжірибелік жұмыстардың нәтижесінде алынған жаңа идея, әдіс немесе өнім. Ал инновация – осы жаңалықтың практикада қолданылып, нақты нәтиже беруі. Мысалы:

- жаңа физикалық құбылысты ашу – жаңалық.
 - ол құбылыс негізінде жаңа құрылғы жасап, оны өндірісте қолдану – инновация. Тағы бір мысал:
 - мұғалімнің жаңа оқыту әдісін ойлап табуы – жаңалық.
 - сол әдісті сабақта қолдану арқылы оқушылардың білім сапасын арттыру – инновация.
- Жаңалықтар әртүрлі формада көрініс табады. Оларға мыналар жатады:
- ғылыми жаңалықтар мен ашылулар;
 - патенттер және авторлық құқық объектілері;
 - жаңа технологиялар мен өндірістік процестер;
 - ұйымдастырушылық және басқару әдістері;
 - ноу-хау (тәжірибелік білімдер жиынтығы);
 - стандарттар, әдістемелер, нұсқаулықтар;
 - маркетингтік зерттеулер нәтижелері.

Мысалы, жаңа материалдың (мысалы, аса берік қорытпаның) жасалуы – жаңалық, ал оны авиация өндірісінде қолдану – инновация болып табылады.

Инновациялық процесс бірнеше негізгі кезеңнен тұрады:

1. Идеяның пайда болуы;
2. Ғылыми зерттеу және тәжірибелік жұмыс;
3. Жаңалықты әзірлеу;
4. Оны өндіріске енгізу;
5. Нарыққа шығару және тарату (инновациялық диффузия).

Инновациялық диффузия – жаңалықтың қоғамда кең таралу процесі. Мысалы, алғашында тек кейбір мектептерде қолданылған электрондық оқулықтар мен онлайн платформалар бүгінде білім беру жүйесінің ажырамас бөлігіне айналды. Білім беру жүйесінде инновациялар оқыту сапасын арттыруға, оқушылардың қызығушылығын дамытуға және олардың шығармашылық қабілеттерін қалыптастыруға мүмкіндік береді [3].

Мысалы:

- ақпараттық-коммуникациялық технологияларды (АКТ) қолдану;
- виртуалды зертханалар арқылы тәжірибелер жүргізу;
- интерактивті тақталарды пайдалану;

- онлайн оқыту платформаларын енгізу.

Физика пәнінде инновациялық әдістерді қолдану оқушыларға күрделі құбылыстарды визуалды түрде түсінуге көмектеседі. Мысалы, компьютерлік модельдеу арқылы электр өрісін немесе механикалық қозғалысты көрсету оқыту тиімділігін арттырады.

Кез келген жаңалықты жасау – жұмыстың тек бір бөлігі ғана. Ең бастысы – оны практикаға енгізу. Инновацияны тиімді енгізу үшін:

- нарық сұранысын зерттеу;
- экономикалық тиімділігін бағалау;
- қолдану мүмкіндіктерін талдау қажет. Мысалы, энергия үнемдейтін технологияларды енгізу тек экономикалық пайда әкеліп қана қоймай, экологиялық мәселелерді шешуге де ықпал етеді.

Қорытынды

Қорытындылай келе, инновация – қоғам дамуының негізгі факторы болып табылады. Ол жаңа идеяларды тәжірибеге енгізу арқылы экономикалық өсуді, ғылыми-техникалық прогресті және әлеуметтік дамуды қамтамасыз етеді. Жаңалық пен инновация ұғымдарын дұрыс түсіну олардың тиімді қолданылуына мүмкіндік береді. Сондықтан қазіргі заман талабына сай әрбір салада инновациялық қызметті дамыту – маңызды міндеттердің бірі.

Кез келген жаңалық – бұл жаңа идея немесе нәтиже, ал инновация – сол жаңалықтың өмірде іске асырылып, нақты пайда әкелуі. Сондықтан инновацияны жаңалықтың соңғы әрі ең маңызды кезеңі деп қарастыруға болады. Бұл мақсаттарға жету үшін мұғалімнің ізденісі, жаңа тәжірибе, жаңа технологиялар қолдану қажеттілігі туындайды. Инновациялық технологияларды қолдана отырып оқыту - таным әрекетін ұйымдастырудың ұтымды формасы. Мақсаты – оқу үрдісінің өнімділігін арттыру. Инновациялық технологияны қолдану: оқып үйрену, меңгеру, өмірге ендіру, дамыту кезеңдері арқылы іске асады. Инновациялық оқыту білімді тереңдетумен қатар, оқушыны оқу әрекетіне жетелеп, олардың оқуға деген ынтасын оятады. Баяндамада оқушының ойлау қабілетін арттыру үшін қолайлы деп санайтын инновациялық технологияларды қолдану әдістері туралы айтылады.

Қазіргі замандағы мұғалімнің алдындағы негізгі басты міндеті - тек қана оқушыларды білім жағынан ғана қалыптастырып қоймай, оқушылардың рухани деңгейін оятып, тәрбиелік құндылықтарын арттырып, пәнге деген қызығушылықтарын дамытуға атсалысу[4].

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АҚПАРАТТЫҚ-КОММУНИКАЦИЯЛЫҚ ТЕХНОЛОГИЯ ҚҰРАЛДАРЫМЕН ФИЗИКАЛЫҚ ПРОЦЕСТЕРДІ МОДЕЛЬДЕУ

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Аннотация: Бұл мақалада мектептегі оқушыларға физиканың ең күрделі бөлімдері электрондық оқулықтар, виртуалды зертханалар, мультимедиялық ресурстар және интернет материалдары физикалық құбылыстарды көрнекі түрде түсіндіруге мүмкіндік беретіні көрсетілген. Мақалада мұндай тәсіл оқушылардың тек дайын білімді қабылдауын ғана емес, оны тәжірибе жүзінде түсініп, зерттеу дағдыларын дамытуына мүмкіндік беретіні негізделген.

Кілттік сөздер: модель, АКТ, виртуалды, дағдылар, зерттеу, инновация.

КІРІСПЕ

Қазіргі кезеңде оқытудың жаңа ақпараттық-коммуникациялық технологияларын (АКТ) меңгеру – білім беру жүйесінің басты талаптарының бірі болып отыр. ХХІ ғасыр ақпараттық технологиялардың қарқынды дамыған дәуірі ретінде сипатталады. Осыған байланысты қоғамның барлық салаларында, соның ішінде білім беру жүйесінде де цифрлық өзгерістер кеңінен орын алуда. Білім беру мазмұнын жаңарту, оны ғылыми-технологиялық негізде ұйымдастыру және оқыту үдерісіне заманауи құралдарды енгізу – бүгінгі күннің өзекті мәселелерінің бірі.

Ақпараттық-коммуникациялық технологиялар білім беру сапасын арттыруда ерекше рөл атқарады. Олар оқу үдерісін тиімді ұйымдастыруға, білім алушылардың танымдық белсенділігін арттыруға және олардың өздігінен білім алу дағдыларын қалыптастыруға мүмкіндік береді. Сонымен қатар, АКТ құралдарын пайдалану арқылы білім беру мазмұны жаңарып, оқыту әдістері жетілдіріледі. Бұл өз кезегінде оқушылардың шығармашылық қабілеттерін дамытып, олардың ақпараттық құзыреттілігін қалыптастыруға ықпал етеді [1].

Қазақстан Республикасының «Білім туралы» Заңында да білім беру жүйесіне жаңа технологияларды енгізудің маңыздылығы атап көрсетілген. Атап айтқанда, оқыту үдерісіне кредиттік технологияларды, қашықтан оқыту жүйесін және ақпараттық-коммуникациялық құралдарды енгізу арқылы білім беру бағдарламаларын еңбек нарығының өзгермелі талаптарына бейімдеу қажеттілігі көрсетіледі. Бұл – білім беру жүйесінің икемділігін арттырып, заманауи мамандарды даярлаудың негізі болып табылады. Қазіргі білім беру жүйесінің ерекшелігі – тек дайын білімді меңгертумен шектелмей, білім алушының өздігінен ізденуіне, үздіксіз дамуына жағдай жасау.

НЕГІЗГІ БӨЛІМ

Осыған байланысты мұғалімдердің де рөлі өзгеруде: олар тек білім беруші емес, білім алушылардың танымдық іс-әрекетін ұйымдастырушы, бағыттаушы тұлға ретінде көрінеді. Сондықтан педагогтардан инновациялық технологияларды меңгеру, өз кәсіби шеберлігін

үнемі жетілдіру талап етіледі. Әлемдік тәжірибеде білім беруді ақпараттандыру – маңызды бағыттардың бірі болып табылады.

Дамыған елдерде оқу үдерісінде АКТ құралдарын тиімді пайдалану білім сапасын арттырудың негізгі тетігі ретінде қарастырылады. Қазақстанда да бұл бағытта бірқатар жұмыстар жүргізіліп, білім беру кеңістігіне жаңа ақпараттық орта енгізілуде. Соның нәтижесінде білім алушылар игеруі тиіс білім, білік және дағдылардың мазмұны жаңарып, көлемі артуда. Физика пәнін оқытуда ақпараттық-коммуникациялық технологияларды қолдану ерекше маңызға ие.

Электрондық оқулықтар, виртуалды зертханалар, мультимедиялық ресурстар және интернет материалдары күрделі физикалық құбылыстарды көрнекі түрде түсіндіруге мүмкіндік береді. Бұл оқушылардың пәнге деген қызығушылығын арттырып қана қоймай, олардың шығармашылық және зерттеушілік қабілеттерін дамытуға ықпал етеді. Физикалық процестерді модельдеу – білім беру үдерісін жаңғыртудың тиімді бағыттарының бірі. Мұндай тәсіл оқушылардың тек дайын білімді қабылдауын ғана емес, оны тәжірибе жүзінде түсініп, зерттеу дағдыларын дамытуына мүмкіндік береді. Әсіресе модельдеу әдісі арқылы күрделі құбылыстарды көрнекі түрде көрсету оқушылардың шығармашылық ойлауын арттырып, ғылыми қызығушылығын қалыптастырады [2].

Мысал ретінде еркін түсу қозғалысын модельдеуді қарастыруға болады. Бұл процесте дененің ауырлық күші әсерінен қозғалысы зерттеледі. Оның математикалық өрнегі төмендегідей сипатталады:

$$s = \frac{gt^2}{2} \quad (1)$$

Мұндағы s – жүрілген жол, g – еркін түсу үдеуі, t – уақыт. Осы формула негізінде компьютерлік модель құрып, дененің уақытқа тәуелді қозғалысын анимация арқылы көрсетуге болады. Мысалы, экранда шардың жоғарыдан төмен құлауын бейнелеп, уақыт өткен сайын жылдамдықтың қалай артатынын график арқылы қатар көрсету оқушыларға процесті терең түсінуге көмектеседі. Физикалық эксперименттерді осындай модельдеу оқытушыға:

- күрделі ұғымдарды қарапайым әрі түсінікті түрде жеткізуге;
- нақты тәжірибені виртуалды ортада қайталауға;
- зерттеу әдістерін кезең-кезеңімен түсіндіруге мүмкіндік береді.

Электрондық оқулықтар осы модельдеуді жүзеге асыратын негізгі құралдардың бірі болып табылады. Олар тек мәтіндік ақпаратпен шектелмей, анимациялар, виртуалды зертханалар, интерактивті тапсырмалар арқылы оқу материалын кешенді түрде ұсынады. Мұндай ресурстардың құрамына теориялық бөлімдер, есептер жинағы, анықтамалық материалдар, тәжірибелік жұмыстарға нұсқаулар және бақылау тапсырмалары кіреді.

Оқытушы үшін электрондық оқулық – үнемі толықтырылып, жетілдіріліп отыратын ашық әдістемелік жүйе. Ал оқушы үшін – өз бетінше білім алуға мүмкіндік беретін тиімді құрал. Сабақ барысында оны жаңа тақырыпты түсіндіруде, үй тапсырмасын орындауда және білімді тексеруде қолдануға болады.

Физикалық тәжірибелерде электрондық оқулықтарды пайдалану физика сабақтарының сапасын арттыруға ықпал етеді. Әрбір тақырыпта теориялық мәліметтермен қатар заңдар мен анықтамалар, сөздіктер, кестелер, ғалымдар туралы мәліметтер және есептер қамтылған. Анимациялық тәжірибелер физикалық құбылыстарды көзбен көріп түсінуге жағдай жасайды.

Сабақ соңында берілетін тест тапсырмалары оқушылардың білімін жедел бағалауға мүмкіндік береді. Нәтижелер пайыздық көрсеткішпен беріліп, оқушы өзінің білім деңгейін бірден көре алады. Бұл олардың пәнге деген қызығушылығын арттырып, өзін-өзі бақылау дағдысын қалыптастырады.

Физикалық процестерді модельдеу – білім алушылардың теориялық білімін тәжірибемен ұштастыратын тиімді құрал. Бұған қосымша ретінде тағы бір маңызды мысалды – тербелмелі қозғалысты (маятник қозғалысын) модельдеуді қарастыруға болады. Қарапайым маятниктің қозғалысы периодты түрде қайталанып отырады және оның периоды мына формуламен анықталады:

$$T = 2\pi \sqrt{\frac{l}{g}} \quad (2)$$

мұндағы (T) – тербеліс периоды, (l) – маятник ұзындығы, (g) – еркін түсу үдеуі. Бұл процесті компьютерлік модельдеу арқылы оқушылар маятник ұзындығын өзгерткенде тербеліс периодының қалай өзгеретінін бақылап, заңдылықты өздері анықтай алады. Мысалы, виртуалды зертханада маятниктің ұзындығын ұлғайтқанда оның тербелу уақытының артатынын анимация және график арқылы бірден көруге болады. Сонымен қатар, уақытқа тәуелді координата немесе жылдамдық графиктерін қатар көрсету оқушылардың түсінігін тереңдетеді. Осындай модельдеу келесі мүмкіндіктерді береді:

- тәжірибені бірнеше рет қауіпсіз түрде қайталау;
- параметрлерді (ұзындық, масса, бастапқы бұрыш) өзгертіп, нәтижені салыстыру;
- теориялық формуланың дұрыстығын тәжірибе арқылы дәлелдеу;
- графиктік талдау жүргізу.

ҚОРЫТЫНДЫЛАР

Электрондық оқулықтарда мұндай модельдер анимация, интерактивті симуляция және виртуалды зертханалар түрінде беріледі. Бұл оқушыларға тек бақылаушы емес, белсенді зерттеуші болуға мүмкіндік береді. Сонымен қатар, мұндай тапсырмалар оқушылардың:

- логикалық ойлауын;
- эксперимент жүргізу дағдыларын;
- себеп-салдар байланыстарын анықтау қабілетін дамытады.

Қорытындылай келе, еркін түсу қозғалысымен қатар тербелмелі қозғалысты модельдеу де физиканы оқытуда маңызды рөл атқарады. Әртүрлі процестерді сандық және графикалық түрде зерттеу оқушылардың пәнді терең әрі саналы меңгеруіне ықпал етеді[3].

Физикалық процестерді модельдеу мен электрондық оқулықтарды тиімді пайдалану оқыту үдерісін жандандырып, оқушылардың зерттеушілік қабілетін дамытады. Бұл тәсілдер білім алушыларды белсенді, дербес және шығармашылықпен жұмыс істейтін тұлға ретінде қалыптастыруға негіз болады. Білім беру жүйесінде ақпараттық-коммуникациялық технологияларды тиімді пайдалану – оқыту сапасын арттырудың, білім алушылардың құзыреттілігін қалыптастырудың және заманауи талаптарға сай бәсекеге қабілетті тұлға тәрбиелеудің негізгі шарттарының бірі болып табылады. Оқушылардың ақпараттық құзырлылығы мен ақпараттық мәдениетін қалыптастыру қазіргі таңда үздіксіз педагогикалық білім беру жүйесіндегі ең көкейтесті мәселелердің біріне айналып отыр.

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ӘОК 372.853

АСҚЫН ӨТКІЗГІШТІКТІ ОҚЫТУДЫҢ ЕРЕКШЕЛІКТЕРІ

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Аннотация: Мақалада жоғары оқу орындарында оқытудың андрагогиялық моделін қолдану қажеттілігі негізделеді. Өмірлік және кәсіби тәжірибесі, сондай-ақ білім беру қызметі тәжірибесі бар ересек адамдардың жоғары оқу орындарына түсу себептері қарастырылды. Университеттің білім беру процесін ұйымдастырудағы осы ерекшеліктерді ескеру оқытушылардың андрагогиялық құзыреттіліктерін дамытудың негізі болып табылады.

Түйінді сөздер: андрагогикалық құзыреттілік, андрагогика, ересектерді оқыту, оқытудың педагогикалық моделі, оқытудың андрагогикалық моделі.

КІРІСПЕ

Қазіргі ғылым мен техниканың дамуы физиканың жаңа бағыттарының қарқынды дамуына алып келді. Солардың бірі – асқын өткізгіштік құбылысы. Бұл құбылыс электр тогының кедергісіз өтуімен сипатталады және ол энергияны үнемдеу мен жаңа технологияларды дамытуда үлкен рөл атқарады. Асқын өткізгіштік тақырыбы мектеп пен жоғары оқу орындарының физика курсына ерекше орын алады. Себебі ол классикалық физика мен кванттық физиканың түйіскен жерінде орналасқан күрделі құбылыс.

Қазіргі кезеңде ғылым мен техниканың қарқынды дамуы адамзат өркениетінің барлық салаларына түбегейлі өзгерістер енгізуде. Әсіресе физика ғылымы жаңа бағыттармен толығып, табиғат құбылыстарын тереңірек түсіндіруге мүмкіндік беретін іргелі зерттеулердің негізіне айналды. Осындай заманауи әрі болашағы зор бағыттардың бірі – асқын өткізгіштік құбылысы болып табылады. Бұл құбылыс алғаш ашылған сәттен бастап-ақ ғалымдардың үлкен қызығушылығын туғызып, қазіргі уақытта ғылыми-техникалық прогрестің маңызды құрамдас бөлігіне айналды[1].

Асқын өткізгіштік – кейбір материалдардың температурасы өте төмен мәндерге дейін төмендеген кезде олардың электрлік кедергісінің толық жойылуымен сипатталатын ерекше физикалық күйі. Мұндай жағдайда электр тогы өткізгіш арқылы ешқандай энергия шығынынсыз өтеді, яғни электр энергиясы жылуға айналмайды және жүйеде жоғалмай сақталады. Бұл қасиет энергетика саласы үшін аса маңызды, себебі қазіргі электр желілерінде энергияның белгілі бір бөлігі тасымалдау барысында жоғалады. Ал асқын өткізгіш материалдарды қолдану осы шығындарды барынша азайтуға, тіпті толық жоюға мүмкіндік береді.

НЕГІЗГІ БӨЛІМ:

Сонымен қатар, асқын өткізгіштік құбылысы тек энергетикада ғана емес, сонымен бірге көптеген жоғары технологиялық салаларда кеңінен қолданылады. Мысалы, медицинада қолданылатын магниттік-резонанстық томография (МРТ) құрылғылары аса қуатты және тұрақты магнит өрістерін қажет етеді, ал мұндай өрістерді дәл асқын өткізгіш катушалар арқылы алуға болады. Көлік саласында магниттік левитацияға негізделген пойыздар үйкеліссіз қозғалып, жоғары жылдамдыққа жетеді. Ғылыми зерттеулерде бөлшектер

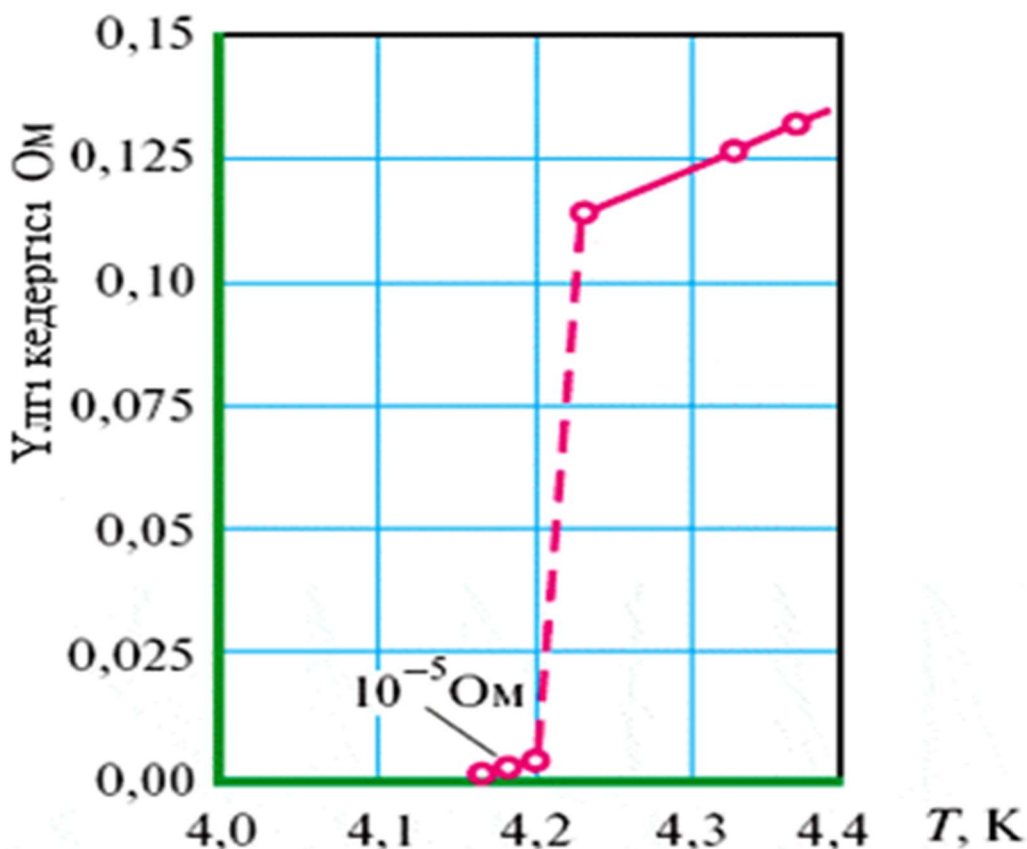
үдеткіштері мен термоядролық қондырғыларда да асқын өткізгіш материалдар маңызды рөл атқарады. Осыған байланысты асқын өткізгіштік – болашақ технологиялардың негізін құрайтын стратегиялық маңызды бағыттардың бірі болып саналады.

Асқын өткізгіштік тақырыбы білім беру жүйесінде, әсіресе мектеп пен жоғары оқу орындарының физика курстарында ерекше орын алады. Оның басты себебі – бұл тақырыптың күрделілігі мен көпқырлылығы. Бір жағынан, ол классикалық физиканың негізгі ұғымдарына, атап айтқанда электр тогы, кедергі, температура және магнит өрісі сияқты түсініктерге сүйенеді. Екінші жағынан, асқын өткізгіштік құбылысы кванттық механика заңдылықтарымен тығыз байланысты. Мұнда электрондардың Купер жұптарына бірігуі, кванттық күйдің қалыптасуы, толқындық функциялардың үйлесімділігі сияқты күрделі ұғымдар қарастырылады. Сондықтан бұл тақырып оқушылардан жоғары деңгейдегі абстрактілі ойлауды және теориялық дайындықты талап етеді.

Осыған байланысты асқын өткізгіштікті оқытуда арнайы әдістемелік тәсілдерді қолдану қажеттілігі туындайды. Атап айтқанда, күрделі физикалық ұғымдарды қарапайым әрі түсінікті тілде жеткізу, көрнекілік құралдарын (схемалар, анимациялар, бейнероликтер) пайдалану, сондай-ақ пәнаралық байланыстарды тиімді ұйымдастыру маңызды рөл атқарады. Сонымен қатар, қазіргі цифрлық технологияларды пайдалану арқылы виртуалды зертханалар мен модельдеулерді енгізу оқушылардың тақырыпты терең түсінуіне мүмкіндік береді.

Асқын өткізгіштік тақырыбын оқытудың тағы бір маңызды аспектісі – оның қолданбалы маңызын көрсету. Оқушылар нақты өмірдегі мысалдар арқылы бұл құбылыстың маңызын түсінгенде, олардың пәнге деген қызығушылығы артады және алған білімдерін практикамен байланыстыра алады. Бұл өз кезегінде олардың ғылыми дүниетанымын қалыптастырып, болашақта инженерлік, техникалық және ғылыми мамандықтарға бағытталуына ықпал етеді. Асқын өткізгіштік – өте төмен температурада электр кедергісінің жойылу құбылысы[2].

Асқын өткізгіштік – бұл кейбір металдар мен қорытпалардың температурасы белгілі бір критикалық мәннен (T_c) төмендеген кезде олардың электр тогына қарсы кедергісі толықтай нөлге тең болатын ерекше физикалық күйі. Мұндай жағдайда электр тогы өткізгіш арқылы ешқандай энергия шығынынсыз, яғни жылуға айналмай, шексіз ұзақ уақыт бойы сақталып аға алады. Бұл құбылыс алғаш рет 1911 жылы нидерланд физигі Хейке Камерлинг-Оннес тарапынан сынапты (Hg) өте төмен температураға дейін салқындату барысында байқалды. Ол кезде сұйық гелий қолданылып, температура шамамен 4,2 К-ге дейін төмендетілген.



Сурет 1. Асқын өткіздік құбылысы.

Осы өте маңызды ғасырлар бойына әлі де ғылыми маңыздылығын жоғалтпаған – асқын өткізгіштік құбылыс алғашқы рет Сурет 1., графикпен сипатталынды [1]. Асқын өткізгіштік күйге өткен материалдар тек электр кедергісінің жойылуымен ғана емес, сонымен қатар ерекше магниттік қасиеттерімен де сипатталады. Олардың ең маңызды ерекшеліктерінің бірі – Мейснер эффектісі, яғни асқын өткізгіштің ішінен магнит өрісін толық ығыстырып шығаруы[3]. Бұл құбылыс нәтижесінде асқын өткізгіш материал толық диамагнетикке айналады. Ом заңы бойынша, яғни тоқтың мәні шексіздікке өсіп кететінің көреміз – осы жағдай асқын өткізгіштік деген құбылыс деп аталды:

$$I = \frac{U}{R} = \frac{U}{0} = \infty$$

ҚОРЫТЫНДЫ:

Физикалық тұрғыдан алғанда, асқын өткізгіштік құбылысы кванттық механика заңдарымен түсіндіріледі. Температура төмендеген кезде өткізгіш ішіндегі электрондар бір-бірімен жұптасып, Купер жұптарын түзеді. Бұл жұптар кристалл торында шашырамай, энергия жоғалтпай қозғала алады. Нәтижесінде электр тогы кедергісіз өтеді. Асқын өткізгіштік тек белгілі бір шарттарда ғана сақталады. Егер: температура критикалық мәннен жоғары көтерілсе, магнит өрісі күшейсе, ток күші шекті мәннен асса, онда материал қайтадан қалыпты өткізгіш күйге өтеді.



Сурет 2. Магниттік левитация.

Қазіргі таңда асқын өткізгіштік құбылысы ғылым мен техникада кеңінен қолданылады. Ол: медицинада (магниттік-резонанстық томография), энергетикада (жоғалтусыз электр тасымалдау), көлікте (магниттік левитация пойыздары), ғылыми зерттеулерде (бөлшектер үдеткіштері), сияқты салаларда маңызды рөл атқарады. Оны оқыту білім алушылардың теориялық білімін тереңдетіп қана қоймай, олардың логикалық ойлау қабілетін, зерттеушілік дағдыларын және заманауи технологияларға деген қызығушылығын дамытуға мүмкіндік береді. Сондықтан асқын өткізгіштікті тиімді оқыту әдістемесін жетілдіру – бүгінгі білім беру жүйесінің өзекті мәселелерінің бірі болып табылады.

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Ақпараттық технологиялар арқылы оқушылардың физикаға қызығушылығын арттыру

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Аннотация: Мақалада жоғары оқу орындарында жаңа ақпараттық технологияның басты тиімділігі – бұл мұғалімге физика сабақтарындағы оқу үрдісін түбегейлі өзгертуге, оқытудағы пәнаралық байланысты күшейте отырып, оқушылардың дүниетанымдарын кеңейтуге және қабілеттерін көре біліп, оны дамытуға толық жағдай жасауы анық көрсетілген.

Түйінді сөздер: білім, тәжірибе, технология, компьютерлік, ақпараттық, шығармашылық, ой өріс.

КІРІСПЕ

Қазіргі жаһандану дәуірінде білім беру жүйесі қоғамның дамуының негізгі қозғаушы күштерінің бірі болып табылады. Әсіресе, ақпараттық технологиялардың қарқынды дамуы білім беру мазмұны мен әдістеріне елеулі өзгерістер енгізуде. Қазақстан Республикасында білім беру жүйесін жаңғыртуға ерекше мән беріліп, оқыту сапасын арттыру, білім алушылардың шығармашылық қабілеттерін дамыту және олардың бәсекеге қабілеттілігін қамтамасыз ету басты міндеттердің бірі ретінде қарастырылуда.

Осы тұрғыда ақпараттық-коммуникациялық технологияларды (АКТ) оқу-тәрбие үдерісіне енгізу – заман талабы. АКТ құралдары білім беруді жаңаша ұйымдастыруға, оқыту тиімділігін арттыруға және білім алушылардың танымдық белсенділігін дамытуға мүмкіндік береді[1].

НЕГІЗГІ БӨЛІМ

Қазақстандағы білім беру жүйесі қазіргі таңда инновациялық бағытта дамып келеді. Бұл үдерісте жаңа технологияларды енгізу ерекше маңызға ие. АКТ-ны қолдану арқылы оқу процесін икемді, қолжетімді және тиімді етуге болады. Ақпараттық технологиялар оқушыларға білімді тек қабылдаушы емес, оны ізденуші, талдаушы және қолданушы ретінде меңгеруге мүмкіндік береді. Сонымен қатар, электрондық оқулықтар, онлайн платформалар, мультимедиялық ресурстар оқу материалын көрнекі әрі түсінікті түрде ұсынуға көмектеседі.

Мұғалімнің кәсіби дамуы және заманауи талаптар. Қазіргі мұғалім тек білім беруші ғана емес, сонымен қатар бағыт беруші, ұйымдастырушы және кеңесші рөлін атқарады. Сондықтан педагогтардың кәсіби дамуы – білім сапасын арттырудың негізгі шарттарының бірі. Мұғалімдердің жаңа технологияларды меңгеруі олардың сабақ беру әдістемесін жетілдіруге ықпал етеді. Бұл өз кезегінде:

- оқыту процесін жаңаша ұйымдастыруға;
- оқушылардың қызығушылығын арттыруға;
- жеке және сараланған оқытуды жүзеге асыруға мүмкіндік береді.

Қазіргі таңда көптеген мектептерде цифрлық ресурстарды пайдалану тәжірибесі кеңінен таралған. Бұл білім беру сапасының артуына оң әсерін тигізуде. Ақпараттық-

коммуникациялық технологияларды қолданудың артықшылықтары өте көп. Олардың ішінде:

- білім сапасының артуы – оқу материалы көрнекі әрі түсінікті беріледі;
- уақытты үнемдеу – ақпаратты жылдам жеткізу мүмкіндігі бар;
- оқушы белсенділігінің артуы – интерактивті тапсырмалар қызығушылықты арттырады;
- жеке оқыту мүмкіндігі – әр оқушының деңгейіне қарай тапсырма беру;
- қашықтықтан оқыту мүмкіндігі – білім алуды кез келген жерде жалғастыру.

АКТ-ны тиімді қолдану мұғалімнің жұмысын жеңілдетіп қана қоймай, білім беру процесінің сапасын жаңа деңгейге көтереді. АКТ қолданудағы қиындықтар мен шешу жолдары. Сонымен қатар, АКТ-ны енгізу барысында бірқатар қиындықтар туындайды:

- техникалық құралдардың жеткіліксіздігі;
- интернет желісінің әлсіздігі;
- мұғалімдердің цифрлық сауаттылық деңгейінің әртүрлі болуы;
- оқушылардың назарын басқа факторлардың бөлуі. Бұл мәселелерді шешу үшін:
- білім беру ұйымдарын заманауи техникалық құралдармен қамтамасыз ету;
- мұғалімдердің біліктілігін арттыру курстарын ұйымдастыру;
- цифрлық ресурстарды тиімді пайдалану әдістемесін жетілдіру қажет[2].

Қазіргі кезеңдегі білім беру жүйесінің қарқынды дамуы педагогтардан тек дәстүрлі оқыту әдістерімен шектелмей, шығармашылық және зерттеушілік тұрғыда жұмыс жүргізуді талап етеді. Бүгінгі ақпараттық қоғам жағдайында мұғалімнің басты міндеті – білім алушыларға заман талабына сай сапалы білім беру ғана емес, сонымен қатар олардың жан-жақты дамуына жағдай жасау. Бұл міндетті жүзеге асыру үшін педагог үнемі ізденіс үстінде болып, жаңашыл әдістер мен технологияларды тиімді қолдана білуі қажет.

Ақпараттық технологиялардың кеңінен қолданылуы оқу процесінің мазмұны мен құрылымына айтарлықтай өзгерістер енгізуде. Компьютерлік құралдар мен цифрлық ресурстарды пайдалану арқылы ұйымдастырылған оқыту оқушылардың логикалық ойлауын дамытып, оларды құбылыстар арасындағы байланыстарды анықтауға және заңдылықтарды түсінуге бағыттайды. Мұндай тәсілдер білім алушылардың танымдық белсенділігін арттырып қана қоймай, олардың болашақ кәсіби қабілеттерінің қалыптасуына да ықпал етеді.

Ақпараттық қоғам жағдайында қолданылатын педагогикалық технологиялар оқыту тиімділігін арттыруда маңызды рөл атқарады. Әсіресе, физика пәнін оқыту барысында ақпараттық-коммуникациялық технологияларды қолданудың артықшылықтары айқын байқалады. Бұл технологиялар оқушылардың өздігінен білім алу дағдыларын дамытуға мүмкіндік береді, оқу уақытын үнемдеуге көмектеседі және білім деңгейін түрлі тест тапсырмалары арқылы жедел бағалауға жағдай жасайды.

Сонымен қатар, шығармашылық есептерді орындау кезінде оқушылар физикалық құбылыстарды тереңірек түсініп, оларды практикамен байланыстыра алады. Қажетті ақпаратқа жылдам қол жеткізу мүмкіндігі де оқу процесінің тиімділігін арттырады. Ең маңыздысы – ақпараттық технологиялар табиғаттағы көзге көрінбейтін немесе күнделікті өмірде бақылау қиын болатын процестерді модельдеу арқылы көрсетуге мүмкіндік береді. Бұл оқушылардың пәнге деген қызығушылығын арттырып, күрделі ұғымдарды жеңіл меңгеруіне жағдай жасайды.

ҚОРЫТЫНДЫ

Қорытындылай келе, ақпараттық-коммуникациялық технологияларды білім беру үдерісінде қолдану – қазіргі заманның басты талаптарының бірі. АКТ құралдары оқыту сапасын арттырып, білім алушылардың танымдық қабілеттерін дамытуға мүмкіндік береді.

Сонымен қатар, мұғалімдердің кәсіби дамуы мен жаңа технологияларды меңгеруі білім беру жүйесінің тиімділігін арттыруда маңызды рөл атқарады. Болашақта білім беру

саласында АКТ-ны кеңінен қолдану арқылы бәсекеге қабілетті, білімді ұрпақ тәрбиелеуге толық мүмкіндік бар.

Білім мен дағдының өзара бірігуі арқылы мұғалім теориялық және практикалық әдістерді саралап пайдалануға жаттығады. Соның нәтижесінде ақпараттық қатынастық технология құралдарын қолдану арқылы оқыту әдістері жүйеленіп берілсе, білім берудің сапасы артады. Оқушыларға алтын уақытыңды орынды пайдаланып, оларға тың мағлұмат, тың дүние беру – ақпараттық қатынастық технологиялардың жетістігі [3]. Жаңа ақпараттық технологияның басты тиімділігі – бұл мұғалімге физика сабақтарындағы оқу үрдісін түбегейлі өзгертуге, оқытудағы пәнаралық байланысты күшейте отырып, оқушылардың дүниетанымдарын кеңейтуге және қабілеттерін көре біліп, оны дамытуға толық жағдай жасауы.

Сабақта компьютерді пайдаланудың тиімділігін былай саралап көрсетуге болады:

- оқушы мен мұғалімнің позитивтік оң қатынаста болуына ықпал етеді. Олай дейтініміз, оқушылар компьютермен тікелей қатысты болғандықтан өзін еркін сезінеді;
- компьютермен жұмыс барысында оқушылардың белсенділік, жауапкершілік және өзіндік шығармашылық қабілеттері қалыптасады. Оқушы өз бетінше еңбектенеді. Өз еңбегінің нәтижесін көреді. Өзін-өзі қадағалауға мүмкіншілік туады.

Бүгінгі таңдағы ақпараттық қоғам аймағындағы оқушылардың ойлау қабілетін қалыптастыратын және компьютерлік оқыту ісін дамытатын жалпы заңдылықтардан тарайтын педагогикалық технологиялардың тиімділігі өте жоғары деп айта аламыз.

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Pedagogical Sciences

Digital Technologies as a Means of Developing Intercultural Communicative Competence in Foreign Language Teaching

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Abstract

In today's media-saturated world, digital technologies play a crucial role in developing intercultural communicative competence in foreign language teaching. By integrating text, audio, video, animation, and interactive resources, digital tools transform learning into a selective, goal-oriented, analytical, and synthetic cognitive activity. They foster critical thinking, independent learning, and problem-solving skills while allowing learners to engage with authentic cultural materials. Through personalized, learner-centered digital environments, students gain autonomy in managing their learning process, selecting and organizing content, and applying it in meaningful intercultural contexts. The dual-channel presentation of information and multi-sensory engagement supports language acquisition, retention, and comprehension, while promoting creativity, adaptability, and collaborative skills. This study highlights the transformative potential of digital technologies as instruments for enhancing both linguistic proficiency and intercultural competence in contemporary foreign language education.

Keywords: *digital technologies, intercultural communicative competence, foreign language teaching, learner autonomy, multimedia learning, cognitive development, digital literacy.*

At present, the use of digital technologies alongside traditional forms of instruction contributes to the development of new skills among learners and enhances their academic performance and motivation. An innovative teacher not only actively employs available platforms and services but also independently creates educational content. At the same time, it should be emphasized that the teacher remains the key subject of the educational process. Only the teacher is capable of designing an appropriate learning trajectory for students, developing educational content, and organizing the learning process in an effective and engaging manner [1].

Digital competence is aimed at developing students' ability to use digital technologies safely, responsibly, and critically, not only in the educational context but also in professional activities and the social environment. The results of the study have shown that the application of digital technologies in visual arts lessons has elevated the educational process to a new level. However, the implementation of innovations may be accompanied by certain challenges. Firstly, the lack of teachers' skills in effectively using digital tools or insufficient time to master them may hinder the full delivery of lessons. In this regard, it is necessary to organize specialized courses and training programs. Secondly, the lack of necessary digital equipment in all schools is also a significant issue, which requires systematic efforts to provide educational institutions with appropriate infrastructure [2].

Digital technologies in contemporary foreign language teaching integrate text, audio, video, animation, spatial models, and images into unified digital content. Emerging from language teaching practice, these innovative methods have opened up new opportunities for foreign language instruction. At the same time, digital tools convey information not only at the cognitive level but also at the emotional and sensory levels, thereby increasing learners' motivation and engagement. By providing a more meaningful learning context, digital technologies enable students to perceive authentic language material in personally relevant formats. In addition, audiovisual materials contribute to the development of learners' character, dialectical thinking, scientific worldview, and internal value orientations. By creating a dynamic and multifaceted learning environment, such tools foster self-awareness, autonomy, and independent learning—key skills for successful integration into modern international society.

It can be argued that the integration of information and communication technologies, digital tools, and internet applications into the process of developing students' communicative competence in a foreign language eliminates the limitations of the traditional classroom, making the learning process more effective and flexible. As learners strive for meaningful interaction with foreign language lesson content, they invest greater effort in understanding and expressing their thoughts in the target language [3].

As noted by B. Andersen, the digital educational environment “constitutes a complex and holistic socio-psychological reality that integrates fundamental psychological and pedagogical conditions, modern technologies, and the necessary software and methodological support, thereby fully sustaining learners' cognitive activity and providing access to information resources.” Such functionality ensures a visually rich and active learning experience, engaging students in the process, enabling individualized instruction, and accelerating the pace of learning—which is particularly important in foreign language acquisition. Digital educational programs stimulate all four aspects of human activity (cognitive, linguistic, physical, and sensory), thereby turning learners into active participants in the learning process and increasing its effectiveness. Multi-level engagement of sensory channels ensures deeper assimilation of material, improving retention and comprehension. Moreover, such technologies provide learners with opportunities to experiment, make mistakes, and learn in a safe and supportive environment, which is essential for the development of communicative competence in a foreign language [4].

According to V.V. Davydov, the “components” of activity are actions [5]. An action is understood as a sequence of steps aimed at achieving a goal. The distinction between action and activity lies in the goal it pursues: activity is motivated, whereas action is goal-oriented. V.V. Davydov defined activity as a complex structure consisting of interrelated actions. In addition to the task that determines the content of an action, it also includes a specific mode of execution, or operation, as described by A.N. Leontiev. From this perspective, it is essential that foreign language teaching be organized in such a way that learners continuously direct their efforts toward specific goal-oriented actions (e.g., meaningful communication, problem-solving, and reflection). Within a digital educational environment, the role of digital technologies in the development of students' communicative competence is not limited to transforming the content of the learning process. The integration of technologies into foreign language teaching influences the entire instructional process, fostering learners' critical thinking, creativity, and collaboration skills. These tools enable the use of authentic materials and real-life situations, providing learners with opportunities to experience language use in natural contexts similar to those in which it is used by native speakers [6].

Firstly, when learners begin working with a digital information resource in order to master its structure and methods of use, it becomes a central element of their learning activity. At the same time, students are typically required to align their behavior with the logic embedded in the resource. This initial stage is crucial, as it is during this phase that digital literacy skills are formed—

the ability to locate, understand, and critically analyze information online—which constitutes the foundation of 21st-century learning. At subsequent stages, learners use various digital resources to solve educational tasks in accordance with their own logic and objectives. Electronic resources become integrated into the didactic process of developing communicative competence in a foreign language within a digital educational environment. Such texts and resources provide opportunities to engage with a variety of interactive exercises aimed at language practice, activation of relevant vocabulary and grammar, stimulation of active learning, and development of intercultural competence [7].

The transformation of an object into a tool involves the development of learners' activity and thinking, enabling them to distinguish between routine actions and operations, as well as to adopt new methods of performing them. By mastering new digital environments and adapting their approaches to the use of digital resources, learners develop not only language skills but also critical thinking, flexibility, and the ability to cope with future challenges in a digitalized world.

In a world saturated with media information, the process of intercultural communication in a foreign language transforms perception into a selective, goal-oriented, analytical, and synthetic activity. Attention parameters—such as focus distance, direction, intensity, and the ability to track distributed information—become deliberate acts of cognitive control. Within the context of digital technologies, this cultivated selective attention encourages learners to critically analyze information, interpret it, and extract meaning in accordance with specific cultural norms, thereby contributing directly to the development of their intercultural communicative competence. Digital tools not only provide access to authentic cultural materials but also engage learners in processing and comparing cultural information, which strengthens their ability to navigate diverse linguistic and social contexts.

The cultivation of independent thinking and the transition to proactive cognitive activity in mastering foreign language communicative competence within a digital learning environment fosters a more meaningful differentiation of students' mental processes. This approach supports the development of autonomy, creative initiative, and intrinsic motivation, aligning with the goals and principles of the systemic-activity approach to education. By stimulating problem-solving and critical thinking, learners acquire not only language skills but also essential life competencies such as adaptability, resilience, and collaboration. In this way, digital technologies act as more than instructional tools—they become platforms for experiential learning where intercultural awareness and cognitive growth occur simultaneously [8].

Within a digital educational space, foreign language learning becomes integrated and learner-centered, allowing students to shape their own learning process and adjust their educational experience according to personal capacities, needs, and preferences. This personalized analytical system enables learners to monitor their own learning needs and inclinations while taking responsibility for selecting tools, methods, and resources. Digital technologies allow students to “replay” or revisit language material as many times as necessary and in forms best suited to their individual perceptual styles. This capacity to focus on the most interesting and engaging elements enhances both motivation and knowledge retention.

When executing projects in a foreign language, students gain autonomy in selecting content related to the study topic and project outcomes. They become active participants in learning—a key condition for the effective application of the systemic-activity approach. Moreover, by actively choosing and creating content, learners develop self-directedness in the learning process, which enhances control over their own education and stimulates the achievement of tangible results [9].

Digital educational resources play a critical role in developing students' communicative competence within a multimedia-based learning environment, simultaneously increasing learner autonomy in the classroom. Learners are encouraged to independently select sources of

information, organize them, determine methods of presentation, and decide how to communicate the outcomes of their work. Higher autonomy does not compromise learning quality, as digital technologies allow the same content to be presented simultaneously in both visual and auditory forms. This dual-channel input engages both verbal and visual memory, providing more comfortable cognitive and affective conditions for knowledge acquisition [10].

The integration of multiple sensory channels through digital technologies offers structural support for language consolidation, making the learning process more dynamic, interactive, and playful. It also allows learners to use individualized pathways for accessing information, thereby accommodating diverse learning styles and enhancing the development of intercultural communicative competence. By combining cognitive engagement with culturally relevant digital content, these technologies not only strengthen language proficiency but also cultivate the analytical, interpretive, and adaptive skills necessary for meaningful participation in intercultural communication.

Conclusion

Digital technologies serve as an effective means of developing intercultural communicative competence in foreign language learning by providing immersive, interactive, and culturally authentic learning experiences. They encourage learner autonomy, critical thinking, and problem-solving while supporting personalized approaches to language acquisition. The integration of digital tools enhances students' ability to understand and navigate diverse cultural contexts, strengthens language proficiency, and cultivates essential skills for active participation in a globalized society.

The Role of Intercultural Communicative Competence in English Language Teaching at School

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Abstract

In the era of globalization and increasing intercultural interaction, the role of foreign language education has expanded beyond the traditional focus on grammar and vocabulary. Today, language learning involves the development of intercultural communicative competence (ICC), which enables learners to communicate effectively and appropriately with individuals from different cultural backgrounds. English, as a global language, serves as a primary medium for international communication in fields such as education, business, science, and technology. Therefore, English language teaching at school must prepare students not only linguistically but also culturally. The purpose of this article is to explore the role and importance of intercultural communicative competence in English language teaching at school. The study examines theoretical foundations of ICC, its components, and its significance in modern education. Furthermore, the article discusses practical methods and strategies that teachers can implement to develop students' intercultural competence in the classroom. The findings suggest that integrating cultural content into language teaching promotes students' communicative skills, cultural awareness, critical thinking, and tolerance toward cultural diversity. Developing intercultural communicative competence in school education prepares learners to participate successfully in multicultural and multilingual environments.

Keywords: *intercultural communicative competence, English language teaching, culture, communication, globalization, school education*

1. Introduction

The twenty-first century has witnessed rapid globalization, technological development, and increased interaction among people from different cultures and linguistic backgrounds. International communication has become an essential part of everyday life in areas such as education, tourism, business, science, and media. As a result, foreign language education has undergone significant changes. Language learning is no longer limited to mastering grammar structures and vocabulary; it now includes understanding cultural norms, values, and communication styles. English has become the most widely used international language in the world. It functions as a lingua franca that connects people from different countries and cultures. According to many researchers, successful communication in English requires not only linguistic competence but also the ability to understand and respect cultural differences. Therefore, modern English language teaching emphasizes the importance of intercultural communicative competence (ICC). Intercultural communicative competence refers to the ability to communicate effectively and appropriately with individuals from different cultural backgrounds. It includes knowledge of cultural practices, attitudes of openness and curiosity, and skills that allow individuals to interpret and relate cultural information. In educational contexts, the development of ICC helps students become more tolerant, culturally aware, and capable of interacting in diverse social environments. Schools play a crucial role in developing intercultural competence because they prepare young learners for participation in the global community. Through English language

lessons, students gain access not only to a new language but also to new perspectives, traditions, and cultural practices. By integrating cultural learning into language education, teachers can help students understand both their own culture and other cultures. Despite the growing recognition of intercultural competence in education, many classrooms still focus primarily on linguistic knowledge. Cultural aspects are sometimes treated as secondary or optional components of language teaching. However, without cultural understanding, communication may lead to misunderstandings or misinterpretations.

The purpose of this article is to examine the role of intercultural communicative competence in English language teaching at school. The article explores theoretical perspectives on ICC, discusses its importance in modern language education, and presents practical strategies for integrating intercultural learning into classroom activities. Understanding and developing intercultural competence will enable students to communicate successfully in a multicultural world.

2. Literature Review

The concept of intercultural communicative competence has been widely discussed in the field of language education and intercultural communication. Researchers emphasize that language and culture are closely interconnected, and effective communication requires knowledge of both linguistic and cultural aspects. One of the most influential scholars in this area is Michael Byram, who developed a comprehensive model of intercultural communicative competence. According to Byram (1997), ICC consists of several components: attitudes, knowledge, skills of interpreting and relating, skills of discovery and interaction, and critical cultural awareness. These components allow learners to engage with people from other cultures while maintaining respect and understanding. Byram argues that language learners should become intercultural speakers rather than imitate native speakers. Intercultural speakers are individuals who can mediate between cultures, interpret cultural differences, and communicate effectively with people from various cultural backgrounds. Another important contribution to the field was made by Claire Kramsch, who emphasized the inseparable relationship between language and culture. Kramsch (1993) introduced the concept of the “third place”, which refers to a space where language learners develop an understanding of both their own culture and the target culture. In this space, learners negotiate meaning and create new cultural perspectives. Research in intercultural communication also highlights the importance of cultural awareness in preventing misunderstandings. Different cultures may have different communication styles, social norms, gestures, and values. For example, direct communication may be considered polite in some cultures but rude in others. Without cultural knowledge, learners may misinterpret messages or unintentionally offend others. In addition, scholars such as Fantini (2000) and Deardorff (2006) emphasize that intercultural competence includes attitudes such as openness, respect, curiosity, and empathy. These attitudes help individuals develop positive relationships with people from diverse cultural backgrounds. Recent studies in language education suggest that integrating intercultural competence into English language teaching improves students’ motivation and engagement. Cultural topics such as traditions, festivals, daily life, and social values make language learning more meaningful and relevant to students’ lives. Furthermore, the Common European Framework of Reference for Languages (CEFR) recognizes intercultural competence as an essential part of communicative competence. The CEFR highlights the importance of sociolinguistic and sociocultural knowledge in language learning. Overall, the literature shows that intercultural communicative competence has become a key concept in modern foreign language education. Teachers are encouraged to integrate cultural learning into language instruction in order to prepare students for real-world communication.

3. Importance of Intercultural Communicative Competence in School Education

The development of intercultural communicative competence has become one of the key objectives of modern education systems around the world. In the context of English language

teaching at school, intercultural competence plays a particularly important role because English functions as a global language used by people from diverse cultural backgrounds. Students who learn English today are likely to communicate with individuals from many different cultures rather than exclusively with native speakers. One of the main reasons for integrating intercultural competence into school education is the growing need for effective communication in multicultural societies. Modern students live in a world where international cooperation, migration, tourism, and digital communication connect people from different countries. As a result, learners must be able to understand cultural differences and communicate respectfully with others. Intercultural communicative competence also helps prevent misunderstandings that may arise from cultural differences. Communication problems often occur not because of language errors but because individuals interpret messages according to their own cultural norms. For example, eye contact, gestures, personal space, and conversational styles can vary significantly across cultures. Students who are aware of such differences are better prepared to interact successfully in intercultural contexts. Another important benefit of intercultural competence is the promotion of tolerance and mutual respect. Learning about other cultures encourages students to appreciate cultural diversity and develop empathy toward people from different backgrounds. In many educational systems, intercultural education is considered an important component of citizenship education because it supports peaceful coexistence in multicultural societies.

In addition, intercultural competence contributes to students' personal development. When learners compare their own culture with others, they gain a deeper understanding of their own cultural identity. This process helps students reflect on their values, traditions, and beliefs while recognizing the diversity of perspectives in the world. Furthermore, integrating cultural content into English language lessons increases students' motivation to learn. Cultural topics such as traditions, food, music, holidays, and daily life make lessons more engaging and meaningful. Students are often more interested in learning about real-life cultural contexts than focusing solely on grammar exercises. Intercultural competence also supports the development of critical thinking skills. When students analyze cultural similarities and differences, they learn to question stereotypes and examine cultural assumptions. Teachers can encourage students to discuss cultural topics, express their opinions, and explore multiple viewpoints.

Finally, the development of intercultural competence prepares students for future academic and professional opportunities. In higher education and international workplaces, individuals frequently collaborate with people from different cultural backgrounds. Students who develop intercultural skills at school are better prepared for such environments.

4. The Role of Teachers in Developing Intercultural Competence

Teachers play a crucial role in promoting intercultural communicative competence in the classroom. They act as facilitators who guide students in exploring cultural diversity and developing the skills needed for effective intercultural communication. One of the most important responsibilities of teachers is to create a classroom environment that encourages openness and respect. Students should feel comfortable expressing their opinions, asking questions, and discussing cultural topics. A supportive learning environment allows learners to explore cultural differences without fear of judgment.

Teachers also serve as cultural mediators. They help students interpret cultural information and understand the meanings behind cultural practices. For example, teachers may explain why certain greetings, gestures, or communication styles are used in particular cultures. Such explanations help students avoid misunderstandings and develop cultural awareness. In addition, teachers should integrate cultural content into language lessons in meaningful ways. Cultural learning should not be limited to occasional discussions about holidays or traditions. Instead, it should be incorporated into various aspects of language teaching, including reading, writing, listening, and speaking activities. Another important role of teachers is to encourage critical

reflection on cultural issues. Teachers can guide students in analyzing cultural texts, discussing stereotypes, and exploring different cultural perspectives. Through these activities, students learn to think critically about culture and communication. Teachers also need to develop their own intercultural competence in order to effectively teach it to students. Educators who are aware of cultural differences and open to diverse perspectives are better equipped to create intercultural learning opportunities in the classroom. Professional development programs can help teachers acquire the knowledge and skills necessary for intercultural teaching. Training workshops, international exchange programs, and collaborative projects with educators from other countries can enhance teachers' intercultural awareness.

Finally, teachers should encourage students to become active participants in intercultural learning. Rather than simply presenting cultural information, teachers can involve students in research projects, discussions, and collaborative activities that allow them to explore cultural topics independently.

5. Teaching Strategies for Developing Intercultural Communicative Competence

The development of intercultural communicative competence in English language teaching requires deliberate pedagogical planning and the use of strategies that integrate linguistic, cultural, social, and reflective dimensions of learning. Intercultural competence cannot be formed through grammar instruction alone, nor can it emerge automatically from exposure to foreign language vocabulary. It must be cultivated through teaching practices that encourage learners to engage with cultural diversity, interpret unfamiliar meanings, reflect on their own cultural assumptions, and participate in communication that goes beyond superficial language use. In the school context, teachers should select methods that do not treat culture as an additional or decorative element of language teaching, but rather as an essential component of communication itself. Language always carries cultural meanings, values, norms, and patterns of interaction. Therefore, the teaching of English should help students understand not only what people say, but also why they say it in a particular way, how communication reflects social relationships, and how cultural expectations influence interpretation.

A variety of teaching strategies can support the development of intercultural communicative competence. These strategies should aim to help students become more observant, open-minded, and reflective. They should also provide opportunities for learners to compare cultures, analyze cultural practices, interpret authentic communicative behavior, and interact with diverse perspectives. The following approaches are particularly effective in promoting intercultural learning in the English language classroom.

5.1 Use of Authentic Materials

Authentic materials represent one of the most effective tools for developing intercultural communicative competence because they expose learners to language as it is naturally used in real social and cultural contexts. Unlike simplified textbook dialogues, authentic resources reflect genuine patterns of communication, including idiomatic expressions, social conventions, humor, emotional tone, and cultural references. Such materials may include newspaper articles, magazine interviews, television programs, films, documentaries, advertisements, restaurant menus, podcasts, songs, blogs, websites, public speeches, online videos, and even social media posts.

The use of authentic materials is especially valuable because it helps students see the close connection between language and culture. Through authentic texts and media, learners begin to understand that words and expressions often carry meanings that are shaped by social norms, historical experience, and cultural values. For example, students may notice differences in politeness formulas, ways of expressing disagreement, forms of address, or communication between people of different ages and social roles. These observations are important because they teach students that successful communication depends not only on grammatical correctness, but also on sociocultural appropriateness. Films and television programs are particularly useful for

intercultural learning because they provide rich visual and auditory information. Students can observe body language, facial expressions, personal space, turn-taking, humor, and patterns of everyday interaction. A classroom discussion after viewing a film scene can focus on questions such as how the speakers show respect, how conflict is expressed, or what social values are reflected in the dialogue. In this way, learners analyze not only the language itself but also the cultural meanings embedded in communication. Songs and podcasts can also deepen students' intercultural awareness. Songs often reflect social realities, emotions, historical experiences, and cultural identities. Podcasts, especially interviews or discussions, can expose students to a variety of accents, perspectives, and topics relevant to contemporary society. When students work with such materials, they engage with living language rather than artificial examples created solely for instructional purposes. In addition, authentic print and online materials can help students explore how culture is represented in everyday life. For instance, newspapers and websites reveal public concerns, social debates, and national priorities. Advertisements can be used to analyze cultural ideals related to success, family, beauty, or lifestyle. Menus and travel brochures may seem simple, but they also reflect food culture, hospitality norms, and patterns of social interaction. However, the use of authentic materials requires careful teacher guidance. Since such resources can be linguistically and culturally complex, teachers should choose materials that are appropriate for students' age, language level, and educational context. Pre-viewing or pre-reading tasks may be necessary to activate background knowledge, clarify key vocabulary, and prepare students for interpretation. During and after the activity, the teacher should encourage analysis, comparison, and reflection rather than passive consumption of information. In this way, authentic materials become a powerful means of helping students understand real language use and the cultural frameworks that shape it.

5.2 Cultural Discussions

Classroom discussions on cultural topics are another important strategy for developing intercultural communicative competence because they create space for reflection, dialogue, and exchange of perspectives. Through discussion, students do not simply receive information about another culture; they actively interpret it, compare it with their own experiences, and learn to articulate their views respectfully. This process is essential for intercultural learning because competence develops not only through knowledge acquisition but also through meaningful interaction and critical reflection.

Teachers can introduce a wide range of topics for cultural discussion, including family traditions, national holidays, food habits, education systems, gender roles, communication styles, social etiquette, attitudes toward time, values related to success, and perceptions of individualism or collectivism. These themes are accessible to school students because they connect directly to everyday life, yet they also open the door to deeper analysis of cultural norms and assumptions. Cultural discussions help students recognize that many behaviors they consider natural or universal are, in fact, culturally conditioned. For example, when discussing family relationships or school discipline, students may discover that what is considered respectful, polite, or appropriate varies across societies. Such realizations challenge ethnocentric thinking and encourage learners to view cultural differences with greater sensitivity and openness. An important advantage of cultural discussions is that they allow students to compare their own culture with others in a thoughtful and structured way. Comparison helps learners become more aware of their own cultural identity while also developing respect for alternative perspectives. Rather than presenting one culture as correct and another as strange, the teacher should guide students toward understanding that cultural practices emerge from different historical, social, and ideological contexts.

In order for discussions to contribute meaningfully to intercultural competence, they should go beyond factual questions and encourage interpretation. Instead of asking only, "What holidays do

people celebrate in Britain?” a teacher might ask, “What do national holidays reveal about a country’s values and history?” or “How are public celebrations similar to and different from those in our country?” These kinds of questions encourage students to analyze cultural meanings rather than merely memorize information. Cultural discussions also develop important communicative skills. Students learn to listen attentively, express agreement or disagreement politely, justify their opinions, ask follow-up questions, and respond to views that differ from their own. In this sense, discussion serves both linguistic and intercultural goals. It strengthens speaking skills while teaching learners how to participate in respectful dialogue across differences. The teacher’s role in cultural discussion is crucial. Sensitive moderation is necessary, especially when topics involve stereotypes, religion, traditions, or social values. The classroom should remain a safe environment in which students can explore complex issues without fear of ridicule. Teachers should also intervene when students make overly general or stereotypical statements, helping them reformulate ideas in a more balanced and evidence-based way. Thus, classroom discussion becomes an arena for developing not only language proficiency but also empathy, critical thinking, and intercultural maturity.

5.3 Role-Playing Activities

Role-playing is an especially effective strategy for developing intercultural communicative competence because it allows students to practice communication in simulated real-life situations. Unlike theoretical discussions alone, role-play places learners in an active position where they must respond, negotiate meaning, interpret social cues, and make communicative choices within a specific cultural context. This kind of experiential learning helps students move from abstract cultural knowledge to practical intercultural performance. In role-playing activities, students may be asked to act out situations such as meeting a foreign guest, participating in a student exchange, attending an international conference, ordering food in another country, resolving a misunderstanding between people from different cultures, or introducing aspects of their own culture to international visitors. These scenarios reflect authentic communicative needs and help students rehearse situations they may face in real life.

One of the key strengths of role-play is that it develops sociolinguistic flexibility. Students learn that appropriate language use changes depending on context, relationship, status, and cultural expectations. For example, the language used when speaking to a teacher, a friend, a shop assistant, or a foreign visitor may differ in terms of politeness, formality, directness, or tone. Through role-play, learners begin to understand that effective communication is not simply about producing correct sentences, but about choosing language that fits the social and cultural situation.

Role-playing also helps students become more sensitive to non-verbal aspects of communication. Gestures, eye contact, silence, facial expressions, and physical distance can all vary significantly across cultures. When students perform intercultural scenarios, they become more aware that communication involves a wide range of signals beyond spoken words. This awareness is especially important because many intercultural misunderstandings arise from non-verbal behavior rather than from vocabulary or grammar mistakes. Another major benefit of role-playing is that it supports empathy and perspective-taking. When learners assume the role of a person from another cultural background, they are encouraged to imagine how that person might think, feel, and respond in a given situation. This process helps reduce prejudice and develops the ability to understand communication from multiple viewpoints. Students begin to see that differences in behavior do not necessarily indicate rudeness or incompetence, but may simply reflect another cultural framework.

For role-playing to be effective, it should be followed by reflection. After the activity, students can discuss what they found difficult, what misunderstandings occurred, how they felt in their roles, and what cultural factors influenced the interaction. This reflective stage is essential because it

transforms performance into learning. The teacher may ask questions such as: What communication strategies were successful? What cultural assumptions influenced your response? How could this situation be handled more effectively in real life?

Thus, role-playing is not just a speaking exercise. It is a dynamic pedagogical method that develops communicative confidence, cultural sensitivity, adaptability, and the ability to interpret and respond appropriately in intercultural encounters.

5.4 Project-Based Learning

Project-based learning is a highly valuable approach to developing intercultural communicative competence because it promotes independent inquiry, collaboration, creativity, and sustained engagement with cultural topics. Unlike short classroom exercises, projects allow students to investigate cultural issues in greater depth and to construct knowledge through research, discussion, and presentation. This makes project work especially suitable for intercultural education, where understanding often requires exploration of complex social and historical contexts.

In project-based learning, students may work individually, in pairs, or in groups to study aspects of cultures associated with the English language or with global communication more broadly. Possible project topics include school life in different countries, traditional and modern celebrations, youth culture, environmental attitudes, food traditions, popular media, family values, or cultural symbols. Students may also compare how a single topic, such as hospitality, education, or gender roles, is understood in different societies. This method is particularly effective because it encourages learners to move beyond passive reception of information. Students become active researchers who search for data, evaluate sources, select relevant examples, and organize their ideas into a coherent product. During this process, they also practice important academic and communicative skills in English, including reading, note-taking, summarizing, discussing, writing, and public speaking.

Project-based learning supports intercultural competence in several ways. First, it develops cultural knowledge by exposing students to specific facts, practices, and viewpoints. Second, it promotes interpretive skills because learners must analyze and explain what they find rather than merely collect information. Third, it strengthens interaction skills when students work collaboratively and negotiate meaning within their group. Finally, it encourages critical cultural awareness, especially when students are asked to reflect on stereotypes, media representation, or the social significance of cultural practices.

For example, a project on “School Life Around the World” may require students to compare classroom behavior, teacher-student relationships, school uniforms, extracurricular activities, and discipline systems in several countries. Such a project helps learners understand that educational systems are shaped by broader cultural values and societal expectations. Another project might ask students to create a presentation on “Cultural Etiquette in International Communication,” focusing on greetings, punctuality, gift-giving, and forms of politeness. This kind of task directly connects cultural knowledge to communicative practice. The final stage of project work is also important. Presentations, posters, reports, digital slideshows, videos, or classroom exhibitions allow students to share their findings with others. This public dimension increases motivation and gives learners an authentic purpose for communication. It also creates opportunities for peer learning, as students are exposed to a variety of topics and perspectives presented by classmates. To maximize the intercultural value of projects, teachers should encourage students to use diverse and reliable sources, ask analytical questions, and avoid simplistic generalizations. Reflection tasks can be added at the end, asking students what they learned about another culture, how their views changed, and what similarities they found with their own society. In this way, project-based learning becomes not only a method of language practice but also a meaningful path toward intercultural understanding.

5.5 Comparative Cultural Analysis

Comparative cultural analysis is a central strategy in the development of intercultural communicative competence because it helps students identify, interpret, and reflect on similarities and differences between cultures. Comparison encourages learners to move beyond isolated facts and toward a deeper understanding of how values, beliefs, and social norms influence communication and behavior. It also strengthens the ability to view one's own culture from a new perspective, which is an essential aspect of intercultural awareness. In the language classroom, comparative analysis may focus on a wide variety of themes, including greetings, family structures, attitudes toward time, classroom behavior, holiday traditions, eating habits, gender expectations, concepts of privacy, or patterns of politeness. Through these comparisons, students begin to understand that everyday practices are not universal but culturally situated. What seems normal in one context may be interpreted differently in another. This strategy is especially useful because it prevents the study of culture from becoming one-sided. Instead of learning only about "other people," students are invited to reflect equally on their own society. Such reflection reduces the tendency to exoticize foreign cultures and helps learners see intercultural communication as a dialogue between perspectives rather than as the observation of something distant and unfamiliar. Comparative cultural analysis also promotes critical thinking. Students are encouraged to ask why differences exist, what historical or social factors may explain them, and how these differences affect communication. For example, when comparing direct and indirect communication styles, learners may explore how concepts such as respect, hierarchy, individual autonomy, or group harmony shape verbal interaction. In this way, cultural comparison becomes interpretive rather than descriptive.

A further advantage of this approach is that it helps students challenge stereotypes. Superficial cultural learning may lead learners to generalize too quickly, but structured comparison encourages them to look for nuance, context, and variation within cultures. Teachers can remind students that no culture is completely uniform and that individual behavior is influenced by many factors besides nationality. This is important in preventing cultural analysis from turning into oversimplification.

Comparative tasks can take many forms. Students may complete charts, write comparison essays, analyze dialogues, discuss photographs, or examine case studies involving intercultural misunderstanding. They may also compare proverbs, idioms, or expressions related to friendship, work, family, or success, which can reveal different cultural worldviews. Such activities develop both linguistic ability and interpretive competence.

When properly guided, comparative cultural analysis helps students become more thoughtful communicators. They learn that successful interaction requires awareness of both common ground and difference, and they become more capable of adjusting their interpretations when encountering unfamiliar cultural behavior. Therefore, this strategy is not only academically valuable but also highly practical for real intercultural communication.

5.6 Digital Communication and Virtual Exchanges

The rapid development of digital technologies has created new and powerful opportunities for fostering intercultural communicative competence in school education. Digital communication and virtual exchanges allow students to interact with peers, teachers, and communities from different cultural backgrounds without leaving the classroom. These experiences make intercultural learning more immediate, personal, and authentic, and they are especially relevant in contemporary education, where online communication has become an integral part of global interaction.

Virtual exchanges may take the form of video conferences, email correspondence, online discussion forums, collaborative class projects, shared digital presentations, or participation in international educational platforms. Through these formats, students can communicate in English

with peers from other countries, discuss common topics, exchange cultural information, and collaborate on joint tasks. This kind of communication transforms English from a school subject into a real means of intercultural connection. One of the greatest benefits of digital communication is authenticity. When students interact with real people from other countries, they encounter genuine language use, diverse accents, spontaneous responses, and differing perspectives. These exchanges help them understand that English is used internationally by speakers with a wide range of cultural and linguistic backgrounds. As a result, learners develop not only fluency but also flexibility, tolerance for ambiguity, and confidence in real communication. Virtual interaction also increases students' motivation. Many learners become more engaged when they know that their communication has a real audience and purpose. Writing an email to a partner school, introducing their country in an online meeting, or collaborating on an international presentation encourages students to use language meaningfully and responsibly. In addition, such activities often promote a sense of curiosity and excitement, since students are learning directly from peers rather than only from textbooks. From an intercultural perspective, digital exchanges help students challenge stereotypes and humanize cultural difference. Instead of relying on generalized descriptions, learners communicate with actual individuals whose opinions, habits, and experiences may be more complex than expected. This direct contact supports empathy and helps students understand that cultures are dynamic, diverse, and lived in personal ways.

However, digital intercultural communication also requires preparation. Teachers should establish clear objectives, select age-appropriate topics, and prepare students for respectful online interaction. Learners may need support in formulating questions, introducing themselves, responding politely, and handling misunderstandings. It is also useful to include reflective tasks after virtual exchanges, asking students what surprised them, what they learned, and how the experience changed their understanding of another culture. There are, of course, practical challenges such as time differences, technical limitations, unequal access to digital tools, and varying language proficiency. Nevertheless, even small-scale digital activities can contribute significantly to intercultural competence if they are carefully designed and integrated into the learning process.

Overall, digital communication and virtual exchanges represent one of the most promising modern strategies for developing intercultural communicative competence. They connect language learning with real-world interaction and help students prepare for participation in an increasingly interconnected global society.

6. Challenges in Teaching Intercultural Communicative Competence

Despite the recognized importance of intercultural competence, teachers often face several challenges when attempting to integrate it into English language teaching. One of the main challenges is the limited time available in school curricula. Language teachers are often required to focus primarily on grammar, vocabulary, and exam preparation. As a result, cultural topics may receive less attention in the classroom. Another challenge is the lack of appropriate teaching materials. Some textbooks include only superficial cultural information or focus mainly on one cultural perspective. Teachers may need to supplement textbooks with additional resources in order to provide a more diverse representation of cultures. Teacher preparation can also present difficulties. Not all educators receive formal training in intercultural communication, which may make it challenging to teach intercultural competence effectively. Furthermore, cultural stereotypes may influence students' perceptions of other cultures. Teachers need to address stereotypes carefully and encourage students to develop a more nuanced understanding of cultural diversity. Technological limitations can also affect intercultural learning opportunities. In some schools, access to digital resources or international communication platforms may be limited.

Despite these challenges, many educators recognize the value of intercultural competence and seek creative ways to incorporate it into their teaching practices.

7. Classroom Applications and Case Studies

Practical application of intercultural communicative competence in the classroom is essential for helping students develop real-life communication skills. While theoretical knowledge of culture is important, students need opportunities to apply this knowledge through interactive activities and meaningful communication.

One effective way to develop intercultural competence is through culture-based classroom projects. For example, students can work in groups to research different countries where English is spoken and present their findings to the class. These projects may include topics such as cultural traditions, national holidays, education systems, cuisine, and social customs. During presentations, students not only practice their English language skills but also learn about cultural diversity.

Another useful classroom activity is the cultural comparison task. In this activity, students compare aspects of their own culture with those of English-speaking countries. For instance, students may compare greeting traditions, family relationships, or school systems. Such activities help students understand both cultural similarities and differences while promoting deeper reflection on cultural identity.

A case study conducted in several secondary schools demonstrated that integrating cultural content into English lessons significantly improved students' motivation and participation. In these classrooms, teachers used authentic materials such as films, songs, online articles, and interviews with people from different countries. Students reported that they found these activities more engaging than traditional grammar-focused lessons.

Another example of intercultural learning involves virtual exchanges with students from other countries. Through video conferencing platforms or online discussion forums, students can communicate with peers who speak English as a foreign language or as a native language. These exchanges allow learners to practice real-life communication while learning about the perspectives and experiences of people from different cultures. For example, a classroom project might involve students collaborating with a partner school in another country to discuss topics such as daily life, education, hobbies, or cultural traditions. Students can prepare questions, share presentations, and engage in conversations in English. Such experiences help students develop confidence in their communication skills while gaining first-hand intercultural experience. Teachers may also use storytelling and literature to introduce cultural topics. Short stories, novels, and poems from different cultures allow students to explore cultural values, historical contexts, and social issues. Literature encourages students to reflect on cultural themes and discuss characters' experiences and perspectives. Another practical approach is the use of problem-solving tasks related to intercultural situations. Students may analyze scenarios where misunderstandings occur because of cultural differences. They then discuss possible solutions and suggest strategies for effective communication. These activities develop students' analytical thinking and intercultural awareness. Furthermore, teachers can organize cultural days or international events in schools. During these events, students present different cultures through food, music, traditional clothing, or performances. Such events promote cultural appreciation and create opportunities for students to learn about global diversity.

Through these practical activities, students gradually develop the skills needed to communicate successfully in intercultural environments. The integration of cultural learning into everyday classroom practice makes language learning more meaningful and relevant.

8. Discussion

The integration of intercultural communicative competence into English language teaching reflects broader changes in modern education. As societies become more interconnected, the ability to communicate across cultures has become a crucial skill for students.

The analysis presented in this article demonstrates that intercultural competence contributes to multiple aspects of student development. It enhances communication skills, encourages cultural awareness, and promotes respect for diversity. Students who develop intercultural competence are better prepared to participate in international communication and multicultural environments.

One important aspect of intercultural learning is the shift from traditional teacher-centered instruction to more interactive and student-centered approaches. Activities such as discussions, projects, role-playing, and virtual exchanges encourage students to actively engage with cultural topics. These methods allow learners to explore cultural differences through personal experience rather than passive memorization.

Another key point is that intercultural competence should not be limited to learning about the cultures of English-speaking countries. In today's globalized world, English is used as a lingua franca among people from many different cultural backgrounds. Therefore, intercultural education should include diverse global perspectives.

It is also important to recognize that intercultural competence is a long-term developmental process. Students gradually develop intercultural awareness through repeated exposure to cultural information and interaction with diverse perspectives. Teachers should therefore incorporate intercultural learning throughout the language curriculum rather than treating it as a single lesson or topic.

Educational institutions and policymakers also play a role in supporting intercultural education. Curriculum guidelines, teacher training programs, and teaching materials should emphasize the importance of cultural learning alongside linguistic competence.

Despite the challenges discussed earlier, the benefits of intercultural communicative competence are widely recognized. Students who develop intercultural skills are more likely to succeed in international academic environments, global workplaces, and multicultural societies.

9. Conclusion

Intercultural communicative competence has become an essential component of modern English language teaching. In a world characterized by globalization and cultural diversity, students need more than linguistic knowledge in order to communicate effectively. They must also understand cultural differences, demonstrate empathy, and adapt their communication strategies in intercultural situations.

This article has examined the role of intercultural communicative competence in English language teaching at school. The study discussed theoretical perspectives on ICC, including key models developed by scholars such as Byram and Kramsch. It also explored the importance of intercultural competence in education, highlighting its role in promoting communication skills, cultural awareness, and tolerance.

The article further examined the role of teachers in fostering intercultural competence and presented practical strategies for integrating cultural learning into classroom activities. Methods such as authentic materials, role-playing, project-based learning, cultural comparisons, and digital communication can help students develop intercultural skills.

Although teachers may face challenges such as limited classroom time, insufficient materials, or lack of training, these obstacles can be addressed through professional development, creative teaching approaches, and the use of modern technologies.

Ultimately, developing intercultural communicative competence prepares students to become responsible global citizens who can interact respectfully and effectively with people from diverse cultural backgrounds. By integrating intercultural learning into English language teaching, schools can equip students with the knowledge, skills, and attitudes needed for successful communication in the globalized world.

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FORMATION OF READINESS OF FUTURE PRIMARY SCHOOL TEACHERS TO APPLY ACTING TECHNIQUES IN FORMAL AND INFORMAL LEARNING CONTEXTS

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Abstract

This article addresses the problem of preparing future primary school teachers to apply theatrical mastery methods in their professional practice. The relevance of the study is determined by the growing need to develop communicative expressiveness, pedagogical interaction skills, classroom management abilities, and the capacity to design engaging learning environments. In this context, theatrical pedagogy is considered as an integrative resource that combines speech development, emotional responsiveness, creativity, and pedagogical improvisation.

The aim of the study is to identify the potential of educational programme courses in preparing future primary school teachers to apply acting techniques within formal and informal learning environments. The research is based on a theoretical analysis of psychological and pedagogical literature, a content analysis of the educational programme and course syllabi, and a comparative analysis of learning outcomes, thematic content, and instructional formats.

The findings indicate that the courses included in the educational programme demonstrate varying degrees of potential in fostering theatrical and pedagogical competencies and can be classified according to their functional roles. The first group includes courses focused on speech and expressive development, forming fundamental skills such as voice control, intonation, and non-verbal communication. The second group comprises methodological courses that facilitate the integration of acting techniques into lesson design and transform them into tools for organizing primary school learning activities. The third group includes psychological and communication-oriented disciplines that support the development of empathy, interaction skills, and reflection, as well as enabling the application of theatrical techniques in informal learning settings.

The results show that the highest effectiveness is achieved through a systematic integration of theatrical mastery into the teacher education process, where different courses perform complementary functions: developing core expressive skills, ensuring methodological transformation, and providing opportunities for practical implementation. The combination of formal and informal learning environments plays a crucial role in enabling students to move from mastering individual techniques to their conscious pedagogical application.

Thus, theatrical mastery can be considered a significant component of professional teacher education, contributing to the development of pedagogical expressiveness, communicative competence, and the ability to design engaging and student-centered learning processes.

Keywords: theatrical pedagogy; primary education; pre-service teacher; formal learning; informal learning; pedagogical communication; dramatization; pedagogical improvisation.

Introduction

The contemporary system of primary school teacher education is oriented not only toward the acquisition of subject-specific and methodological knowledge but also toward the development of communicative expressiveness, emotional resilience, the ability to engage in pedagogical interaction, design active learning, and maintain a positive psychological climate in the classroom. In this regard, theatrical pedagogy acquires particular significance, as it integrates speech development, imaginative thinking, игровое действие, empathy, and reflection.

The increasing complexity of modern educational environments requires future primary school teachers to possess not only subject knowledge but also well-developed communicative, emotional, and interactional competencies. Contemporary pedagogical practice emphasizes the creation of engaging, student-centered learning environments, in which the teacher acts as a facilitator of active participation, collaboration, and meaningful learning.

Within this context, the development of pedagogical expressiveness, communicative flexibility, and the ability to manage classroom interaction becomes a key component of professional training. However, traditional approaches to teacher education are predominantly focused on theoretical instruction and methodological knowledge, while insufficient attention is paid to the development of expressive, embodied, and interactional aspects of teaching practice.

Theatrical pedagogy represents a promising direction that can address these limitations. The integration of acting techniques—such as improvisation, role-play, expressive speech, and dramatization—creates conditions for experiential learning, emotional engagement, and reflective practice. These methods allow future teachers to simulate real pedagogical situations, experiment with communicative strategies, and develop adaptive professional behavior.

At the same time, the potential of theatrical pedagogy in teacher education remains insufficiently explored in terms of its systematic integration into educational programmes. In many cases, acting techniques are applied episodically or within isolated disciplines, which limits their impact on the formation of sustainable professional competencies.

Theoretical Background

Recent international research confirms the relevance of integrating drama-based practices into initial teacher education. Studies have demonstrated that programmes based on creative drama and forum theatre contribute to the development of empathy, awareness of professional conflicts, and socio-ethical reflection among future teachers. Intensive creative drama courses have also been shown to enhance students' creative pedagogy, professional identity, and conscious use of verbal and non-verbal means of pedagogical action. Drama and improvisation are further considered as resources for developing creativity and flexibility in teachers' professional behavior.

Particular attention should be paid to the digital transformation of theatrical pedagogy. Research indicates that digital technologies can enhance the interactivity and engagement of drama-based practices in educational settings. This includes the use of digital storytelling, video-based role-play, hybrid reader's theatre, and multimodal projects. However, digital tools should complement rather than replace embodied dramatic interaction.

Additional significance is found in studies on arts-based approaches and communication in teacher education. Arts-oriented approaches contribute to the development of confidence, interdisciplinary thinking, and readiness for innovation. Drama-based practices activate learning by involving students in action, decision-making, and collective meaning-making. Furthermore, research on listening and communication emphasizes the importance of trust, relational quality, and well-being in effective interaction, which is directly relevant to teacher preparation.

In the scholarly literature, theatrical pedagogy is conceptualized as a space for developing pedagogical artistry, professional communication, and creative individuality. Pedagogical artistry is understood not as an external effect but as a professionally significant quality that ensures expressiveness, emotional authenticity, and productive interaction with learners. Within this framework, acting techniques, role modeling, improvisation, and expressive speech serve as key means of professional development.

Concept of Theatrical Pedagogy

The purpose of this study is to identify the potential of educational programme courses in preparing future primary school teachers to apply theatrical mastery methods within formal and informal learning contexts.

The findings indicate that theatrical pedagogy can be considered an effective means of developing key professional competencies in future teachers. The analysis of the educational programme demonstrates that different disciplines contribute to this process in complementary ways, supporting the development of expressive speech, pedagogical interaction, and methodological flexibility.

A significant result of the study is the identification of a functional distribution of roles among disciplines. Speech-oriented courses form foundational skills related to voice, intonation, and non-verbal communication. Methodological courses ensure the transformation of acting techniques into instructional tools, while psychological and communication-oriented disciplines create conditions for the development of empathy, reflection, and interaction.

The results also highlight the importance of integrating theatrical pedagogy into both formal and informal learning. Formal learning ensures the structured acquisition of knowledge and skills, whereas informal learning provides opportunities for experimentation, creativity, and personal engagement. Their combination facilitates the transition from mastering individual techniques to their conscious application in professional practice.

Furthermore, acting techniques contribute not only to the development of communicative skills but also to the formation of professional identity and pedagogical confidence. Participation in simulated pedagogical situations enables future teachers to respond flexibly to classroom dynamics and design engaging learning experiences.

At the same time, the effectiveness of theatrical pedagogy depends on its systematic and interdisciplinary implementation. When acting techniques are integrated across multiple disciplines and aligned with learning outcomes, they become a sustainable component of professional training rather than an auxiliary element.

Thus, theatrical pedagogy can be considered a strategic resource in teacher education, contributing to the development of comprehensive professional competencies and preparing teachers to work in complex and dynamic educational environments.

Methodology

The methodological framework of the study includes a theoretical analysis of domestic and international literature, a content analysis of the educational programme and course syllabi, and a comparative analysis of learning objectives, outcomes, thematic content, and instructional formats. The analysis was structured around three key questions: which disciplines possess direct theatrical-pedagogical potential; which courses allow the integration of acting techniques into primary education; and which disciplines provide psychological, communicative, and creative support for this process.

Programme Analysis

The analysis revealed that the disciplines of the educational programme can be divided into three interrelated groups. The first group includes courses with a direct theatrical and speech-oriented focus, such as theatrical pedagogy, pedagogical rhetoric, and speech development

practicum. These courses form the basic toolkit of the future teacher, including voice technique, intonational expressiveness, stage presence, role-play, and pedagogical improvisation.

The second group consists of methodological disciplines that integrate theatrical mastery into primary education, including teaching methods of literary reading, children's literature, language education methodology, and teaching technologies. These disciplines transform acting techniques into tools for lesson design and pedagogical practice.

The third group includes psychological, communicative, and creative support courses, such as psychology of interaction and communication in education, theory of воспитательной работы, and teaching practice. These courses create conditions for the development of empathy, communication, and reflective skills, enabling the application of theatrical techniques in informal learning environments.

Classification of Disciplines and Model

Long-term experience in teacher education at Abai Kazakh National Pedagogical University enabled the implementation of the updated programme B01308 Primary Education (IP) in the 2025–2026 academic year. The analysis of previous teaching practices and current programme content allowed the identification of disciplines with the highest potential for applying theatrical pedagogy.

The proposed model of integrating acting techniques into teacher education includes three complementary types of learning: formal, informal, and non-formal. Formal learning is implemented through core disciplines that develop expressive and communicative skills. Informal learning is represented by methodological and psychological courses that integrate acting techniques into pedagogical practice. Non-formal learning includes extracurricular activities such as theatre studios, literary events, and educational projects, providing opportunities for practical application and consolidation of skills.

Thus, the integration of these three learning types ensures the transition from mastering acting techniques to their conscious and professional application in teaching practice.

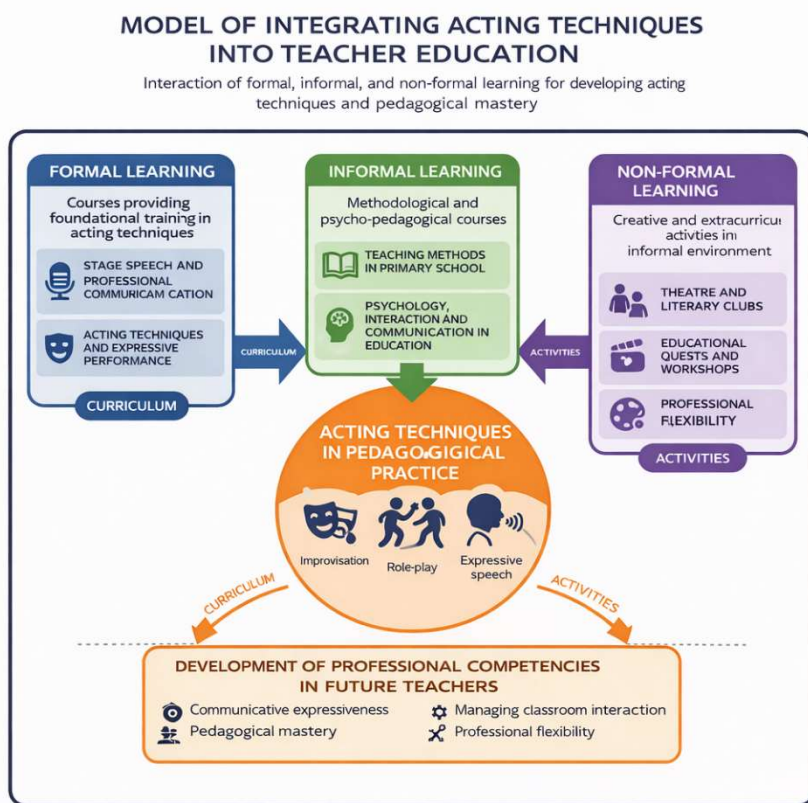


Figure 1. Model of Integrating Acting Techniques into Teacher Education

The systematization of the identified potential of the programme disciplines is presented in Table 1.

Table 1. Potential of the Educational Programme B01308 Primary Education (IP) in Preparing Future Primary School Teachers to Apply Theatrical Mastery Methods

Course	Potential for Formal Learning	Potential for Informal Learning	Acting Techniques	Function in the Training Model
Psychology, Interaction and Communication in Education	Very high	High	active listening, role-play, non-verbal expressiveness, public speaking, forum theatre	development of communicative and emotional foundations of professional activity
Methods and Technologies of Teaching Primary School Students	High	High	game-based modelling, storytelling, theatrical case studies, group improvisation	methodological transformation of acting techniques into lesson design and extracurricular activities
Methodology of Teaching Literary Reading	Very high	High	expressive reading, role-based reading, dramatization, staging, reader's theatre	formal integration of theatrical mastery into subject content
Pedagogical Rhetoric / Speech Practice	Very high	High	speech technique, diction, intonation, pausing, logical stress, voice control	development of professional expressive speech
Teaching Practice	Very high	High	pedagogical improvisation, classroom stage management, expressive speech, role interaction	practical implementation of theatrical-pedagogical techniques in real educational settings

The presented systematization allows several conclusions to be drawn.

First, the potential of theatrical mastery methodology in the preparation of future primary school teachers has an interdisciplinary nature.

Second, the most effective model is one in which theatrical-pedagogical practices are distributed across disciplines according to their functions: speech training, psychological and communicative support, methodological integration, and practical implementation.

Third, it is precisely the combination of formal and informal components that ensures a sustainable professional effect—from mastering techniques to their conscious pedagogical application.

Discussion

Within the context of this study, the formulations *“training future primary school teachers in formal and informal learning environments using theatrical pedagogy”* and *“training future primary school teachers to apply theatrical pedagogy in formal and informal learning environments”* are considered complementary rather than contradictory.

The first formulation emphasizes the organization of professional training, in which elements and tools of theatrical pedagogy are already embedded. The second highlights the

intended outcome of this training—the formation of readiness among future teachers to independently and pedagogically appropriately apply theatrical methods in their professional practice.

Thus, both formulations describe a unified process: teacher education is carried out through theatrical pedagogy while simultaneously aiming to develop the ability to apply it in classroom, extracurricular, educational, and communicative contexts.

The analysis of the educational programme demonstrates that the preparation of future primary school teachers to apply theatrical mastery can be structured as an integrated system. Its core consists of disciplines with a direct theatrical and speech-oriented focus. Methodological integration is ensured by courses related to literary reading, language education, and active learning approaches. The psychological, communicative, and creative block creates conditions for the informal acquisition of theatrical practices, while teaching practice serves as a space for their real-world application.

Such a model allows theatrical mastery to be considered as a significant resource for developing pedagogical speech, empathy, creative teaching identity, and the ability to design engaging learning experiences for primary school students.

Conclusion

The study confirms that theatrical mastery represents a valuable pedagogical resource in the professional training of future primary school teachers. The analysis of the educational programme demonstrates that different courses contribute to this process in complementary ways, supporting the development of expressive, communicative, and methodological competencies.

The integration of acting techniques into formal and informal learning enhances students' ability to engage learners, manage classroom interaction, and design meaningful educational experiences. The findings highlight the importance of a systematic and interdisciplinary approach, where theatrical pedagogy is embedded across multiple courses rather than treated as an isolated element.

Such an approach ensures the transformation of individual techniques into sustainable professional skills applicable in real teaching contexts.

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DIGITAL PEDAGOGICAL APPROACHES TO TEACHING SPEAKING SKILLS IN EFL HIGHER EDUCATION

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Abstract

This study investigates the impact of gamification on students' speaking fluency in English as a Foreign Language (EFL) contexts. The research aims to identify key trends, dominant themes, and research gaps in the field by conducting a systematic review and bibliometric analysis of Scopus-indexed publications from 2005 to 2025. A total of 143 publications were initially identified, of which a refined sample was selected following PRISMA guidelines to ensure methodological relevance and quality. The findings reveal a significant increase in scholarly interest in gamification and digital learning environments, particularly after 2015, reflecting the growing integration of technology into language education. The thematic analysis indicates that gamification, motivation, and student engagement represent the core research areas, while speaking fluency remains an emerging and underexplored topic. The keyword co-occurrence network demonstrates that gamification is closely associated with educational technologies, learner psychology, and motivational factors, highlighting its multidimensional nature. The results further show that gamification enhances speaking fluency by increasing learners' motivation, reducing anxiety, and promoting active participation in communicative tasks. Game-based elements such as rewards, challenges, and interactive activities contribute to a more engaging and supportive learning environment, fostering students' confidence and willingness to speak. However, the effectiveness of gamification depends on factors such as instructional design, teacher competence, and alignment with learning objectives. The study concludes that gamification is a promising pedagogical strategy for improving speaking fluency in EFL contexts. At the same time, it identifies a critical research gap in empirical studies focusing specifically on oral communication skills, suggesting the need for further experimental and longitudinal research.

Keywords: gamification; speaking fluency; EFL learning; student motivation; digital learning; game-based learning; language education.

Introduction

Relevance of the research. Over the past several years, one of the most high-priority in English language teaching is the inadequate development of students' speaking fluency. Despite using many communicative methods, many students often have difficulty expressing their thoughts clearly, confidently, and spontaneously in English. This issue is particularly acute when learning English as a foreign language, as limited contact with native speakers in real life limits opportunities for practical language use. The situation is further exacerbated by students' low motivation and insufficient information during speaking practice, which, in turn, negatively impacts their public speaking skills. Traditional teaching methods frequently fail to create interactive and meaningful learning environments, leading to passive participation and increased

speaking anxiety. The growing trend toward digital technologies and modern educational resources dictates the need to implement innovative approaches to learning that will enhance student engagement. In this regard, gamification is emerging as a promising pedagogical strategy. The addition of game elements such as points, badges, competitions, and rewards transform traditional learning into an engaging and motivating process. Although research demonstrates that gamified learning environments can reduce anxiety, increase engagement, and boost student confidence, which positively impacts oral fluency development, a comprehensive study of the impact of gamification on oral fluency in EFL classrooms has not yet been conducted.

This study aims to explore the role of gamification in enhancing students' speaking fluency in learning English, with a particular focus on its influence on learners' motivation, engagement, and communicative performance. Specifically, the research examines:

- the effectiveness of gamification strategies in improving speaking fluency;
- the impact of game elements on students' motivation and participation;
- the role of digital tools in supporting oral communication skills.

The purpose of this research is to provide a scientific justification for the use of gamification as an effective pedagogical approach to enhance students' speaking fluency and to determine its effectiveness through a systematic review of studies published between 2005 and 2025. The research question is: *how does gamification influence students' speaking fluency in learning English?*

The focus of the study is on the development of speaking fluency in students within EFL classrooms. The focus of the study is on utilizing gamification as an educational tool to enhance students' speaking abilities. This study's importance is found in its addition to the realm of English language education by offering theoretical and empirical proof regarding the benefits of gamification in enhancing speaking fluency. The results of this study could provide actionable suggestions for teachers on incorporating gamified tasks into their instructional methods to enhance student motivation and involvement. Additionally, the research aids in the creation of novel teaching strategies amid the digital transformation in education and promotes the enhancement of communicative skills among students.

Literature Review

The integration of gamification into English as a Foreign Language instruction has emerged as a significant pedagogical approach to enhancing students' speaking fluency, widely recognized as one of the most complex and demanding language skills. Speaking fluency requires not only linguistic knowledge but also real-time processing, spontaneous production, and the ability to interact effectively in communicative contexts. However, traditional classroom practices often fail to provide sufficient opportunities for meaningful oral interaction, leading to low motivation, high anxiety, and limited speaking performance among learners. In response to these challenges, gamification, defined as the use of game design elements such as points, badges, levels, rewards, and feedback systems in educational contexts, has gained increasing attention as a strategy to transform passive learning into active, engaging, and communicative experiences (Christopoulos & Mystakidis, 2023). From a theoretical perspective, the effectiveness of gamification in developing speaking fluency can be explained through several complementary frameworks. Self-Determination Theory posits that learners demonstrate higher levels of engagement and performance when their psychological needs for autonomy, competence, and relatedness are satisfied. Empirical evidence suggests that gamified speaking tasks enhance intrinsic motivation, encouraging learners to participate voluntarily in oral communication and increasing their willingness to communicate (Song, 2025; Ameen, 2025).

In addition, the Broaden-and-Build Theory highlights the role of positive emotions in expanding cognitive and linguistic capacities. Gamified environments reduce anxiety and create emotionally supportive conditions, enabling learners to take communicative risks and produce

more fluent and spontaneous speech (Cheng, 2024; Christopoulos & Mystakidis, 2023). Furthermore, Social Constructivism emphasizes the importance of interaction and collaboration in language learning. Studies indicate that gamified activities, such as role-plays, missions, and group challenges, promote negotiation of meaning and peer interaction, which significantly contribute to speaking development (Rahnama et al., 2016). Similarly, Communicative Language Teaching supports the use of meaningful and authentic communication, and gamification aligns with this approach by embedding speaking tasks within purposeful and interactive contexts (Lee, 2023). A substantial body of empirical research demonstrates that gamification has a positive impact on speaking fluency. Learners engaged in gamified speaking tasks show increased speech rate, reduced pauses, and improved continuity of speech. For instance, Yaghoubi and Kazemi (2023) found that learners participating in online gamified environments produced more fluent speech with fewer hesitations. Likewise, Marín-Pacurucu (2022) reported that students exposed to mission-based speaking activities became more spontaneous and confident in expressing their ideas. Juárez (2024) further observed that beginner-level learners developed the ability to produce longer and more coherent utterances after participating in gamified interventions. In technologically enhanced contexts, Pituxcoosuvarn et al. (2025) demonstrated that AI-supported gamified tasks significantly improved not only fluency but also complexity and accuracy, indicating the potential of integrating advanced digital tools into language learning.

These findings collectively suggest that repeated oral practice, immediate feedback, and interactive engagement embedded in gamification create optimal conditions for developing fluent speech. In addition to fluency, gamification has been shown to improve speaking accuracy, including pronunciation, grammar, and lexical use. Research indicates that repetitive speaking practice within game-based environments allows learners to refine their language production without the pressure of formal evaluation. Marín-Pacurucu and Argudo (2022) found that learners participating in collaborative gamified tasks demonstrated improved pronunciation accuracy and reduced phonological errors. Similarly, studies published in *Ciencia Latina* (2024) revealed that game-based pronunciation activities significantly enhance learners' articulation and phonological awareness. Yaghoubi and Kazemi (2023) also reported improvements in grammatical accuracy, suggesting that increased speaking frequency contributes to the internalization of language structures. Therefore, gamification supports both fluency and accuracy by providing a context in which learners can practice language naturally and repeatedly. Motivation and engagement are identified as central mechanisms through which gamification influences speaking development. Gamified learning environments transform speaking tasks into meaningful and enjoyable experiences, encouraging learners to participate actively rather than passively. Safitri and Tari (2022) demonstrated that gamification increases learner engagement by incorporating elements of competition, collaboration, and achievement. Ameen (2025) further emphasized that emotional engagement enhances cognitive processing and facilitates faster lexical retrieval, leading to more fluent speech production. In a comprehensive meta-analysis, Lee (2023) confirmed that gamification consistently improves learner motivation across various educational contexts, reinforcing its effectiveness as a pedagogical tool. Another important contribution of gamification is the reduction of speaking anxiety, which is widely recognized as a major barrier to oral proficiency. Chen (2022) found that learners in gamified classrooms experience lower levels of anxiety and demonstrate a greater willingness to participate in speaking activities. Similarly, Cheng (2025) reported that gamification creates a supportive and low-stress environment where learners feel less afraid of making mistakes. This shift in perception from speaking as a high-stakes performance to speaking as a collaborative and engaging activity allows learners to focus on communication rather than accuracy, thereby enhancing fluency. Despite the growing body of evidence supporting the effectiveness of gamification, several research gaps remain. Many studies are limited by short intervention durations, making it difficult to determine

the long-term impact of gamified instruction on speaking development. In addition, there is a lack of standardized assessment methods, particularly the use of Complexity, Accuracy, and Fluency (CAF) measures and CEFR-based descriptors, which limits the comparability of findings across studies. Furthermore, the integration of AI-supported gamification remains underexplored, especially in developing educational contexts. Many studies also fail to distinguish clearly between improvements in fluency and accuracy, often reporting general speaking improvement without detailed analysis. Finally, small sample sizes and limited participant diversity reduce the generalizability of results. These limitations highlight the need for more rigorous, longitudinal, and data-driven research that integrates advanced technological tools and standardized evaluation frameworks. Overall, the literature consistently demonstrates that gamification is an effective pedagogical strategy for enhancing EFL speaking fluency by increasing motivation, reducing anxiety, and providing meaningful opportunities for communicative practice. However, further research is required to address existing methodological limitations and to explore the long-term and technology-enhanced potential of gamified language learning.

Methods

This study employed a systematic literature review to investigate the impact of gamification on students' English-language speaking fluency. The review followed a structured and transparent procedure based on the PRISMA methodology to ensure the reliability, validity, and reproducibility of the research process. The data were collected from the Scopus database, which was selected due to its high-quality indexing of peer-reviewed international publications. The search strategy was developed using predefined keywords and Boolean operators to capture relevant studies related to gamification and speaking fluency. The following search query was applied:

TITLE-ABS-KEY ("gamification" AND "speaking") AND PUBYEAR > 2012 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE, "English"))

The initial search yielded 612 records, which underwent a multi-stage screening process. First, duplicate records and studies identified as irrelevant through automated filtering tools were removed (n = 284). Following this, the remaining studies were screened based on titles and abstracts, resulting in the exclusion of 81 records that did not align with the research topic. In the next stage, 247 full-text articles were sought for retrieval; however, 63 reports were not accessible, reducing the number of studies available for eligibility assessment. A total of 184 studies were then evaluated in detail according to predefined inclusion and exclusion criteria. Studies were excluded if they focused on non-EFL contexts, did not address speaking skills, or lacked empirical data (n = 41 total exclusions across categories). As a result of this systematic selection process, 143 studies were included in the final review. These studies were considered methodologically reliable, contextually relevant, and directly aligned with the research objectives. The selected literature encompassed experimental, quasi-experimental, and mixed-methods studies conducted across various educational contexts, including primary, secondary, and higher education. The analysis of the selected studies was conducted using a qualitative synthesis approach, focusing on identifying common themes, theoretical frameworks, methodological patterns, and research gaps. Particular attention was given to key variables such as speaking fluency, motivation, anxiety reduction, and communicative engagement. The application of the PRISMA framework ensured a transparent and systematic approach to literature selection, enabling a comprehensive and evidence-based understanding of gamification's role in enhancing speaking fluency. To comprehensively address the research problem and uncover gaps in the literature, a multi-level procedure was implemented. Initially, a systematic bibliometric analysis was conducted on scientific publications found in the Scopus database. This was followed by an

in-depth content analysis of the selected articles, systematically examining their theoretical bases, methodological approaches, research outcomes, and limitations. The PRISMA methodology (Figure 1) was utilized to ensure the proper identification, evaluation, and selection of scientific evidence relevant to the research topic.

As shown in Figure 1, we limited the search to English-language publications published between 2005 and 2025. A search using the main keywords yielded 612 articles. We then removed 284 duplicates and automatically filtered the remaining ones, allowing us to further examine 328 studies. After a thorough review of titles and abstracts, 81 articles were excluded as they were deemed of limited relevance. We attempted to retrieve 247 full-text articles, but 63 were unavailable.

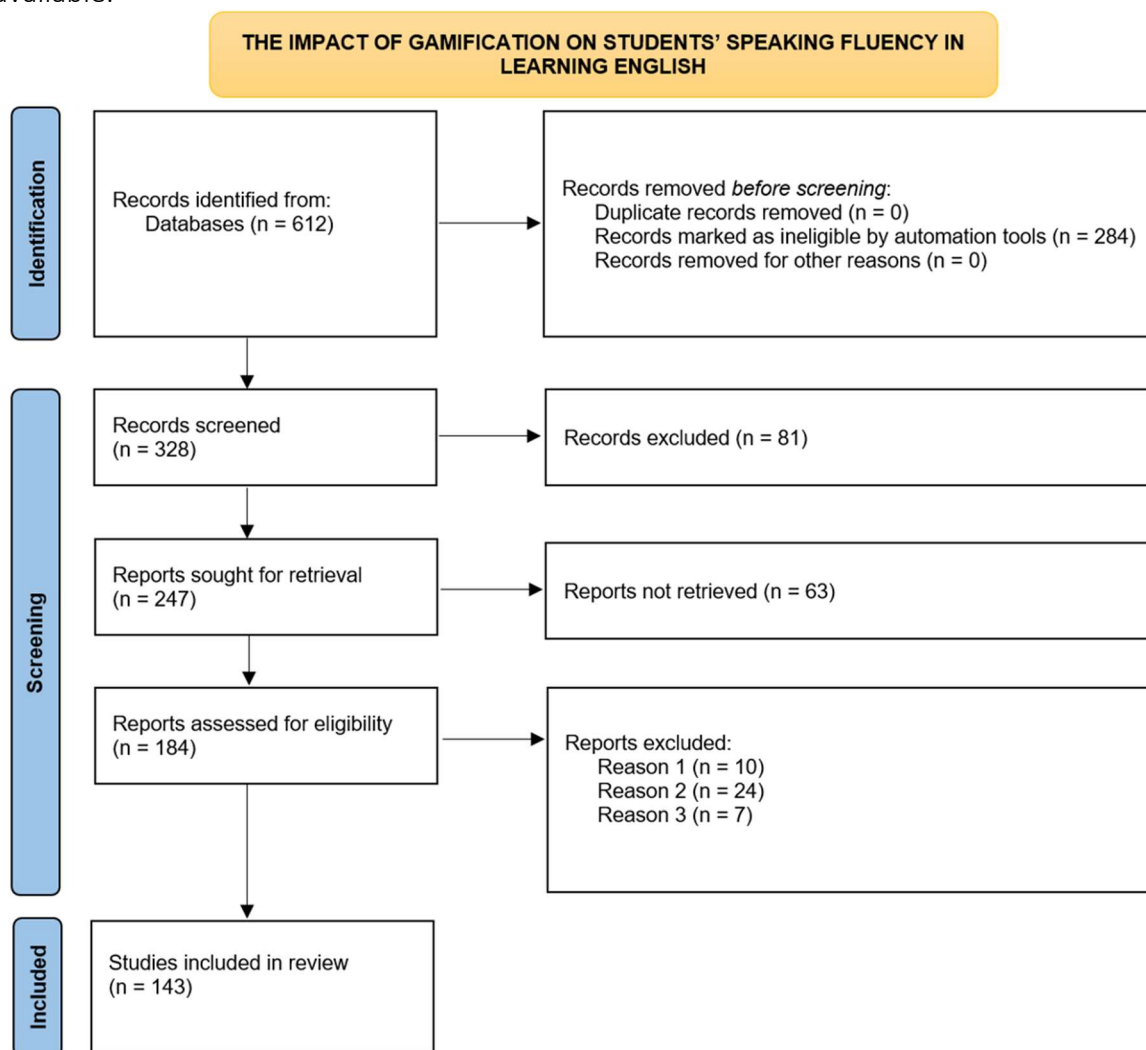


Figure 1. - PRISMA flow diagram for the identification and selection of studies on gamification and students' speaking fluency in EFL learning

This left 184 studies that could be assessed according to the predefined criteria. At this stage, we excluded studies for various reasons, including insufficient representation of the study population, lack of empirical focus, or inappropriateness to the research topic. A total of 143 studies were included in the final analysis. These selected publications were methodologically screened.

Results and Discussion

This section describes the results of a bibliometric and content analysis of scientific publications investigating the impact of gamification methods on improving students' fluency in English language teaching. The data were obtained from a systematic search, selection and

evaluation of sources in the Scopus database using the PRISMA methodology. Out of 612 identified publications, the refined selection process resulted in the inclusion of 143 studies that fully met the thematic and methodological criteria of this study. Analysis of publication trends from 2005 to 2025 shows a steady increase in scientific interest in gamification in foreign language teaching. In the initial period (2005–2016), the number of publications was relatively low, reflecting the early development of this research area in the academic community. However, after 2017, a significant increase began to be observed, due to the integration of digital technologies into education and the popularity of gaming platforms for language learning, such as Kahoot, Quizizz and Duolingo. The period between 2020 and 2024 saw the most significant growth in publishing activity. These trends can be attributed not only to the global digitalization of education, driven by the need to transition to distance learning, but also to the growing adoption of interactive and motivational learning strategies. These notable achievements highlight the role of gamification as a central pedagogical approach to increasing student engagement and learning outcomes. In addition to the increase in the number of publications, there has been a significant increase in citation frequency, which confirms that this topic is of significant academic value. Thus, gamification is recognized not only as a practical teaching method, but also as an important theoretical framework in the fields of pedagogy, psychology, and applied linguistics. In addition, the bibliometric analysis revealed a wide geographical distribution of research works, which highlights the global relevance and applicability of this educational strategy.

Most papers are published from countries such as Spain, China, and Malaysia, indicating a high level of research interest in gamification in these regions. Numerous studies are conducted in Switzerland, Germany and Saudi Arabia. Moreover, research in this field is increasing rapidly in countries such as India, Iran, and Portugal. This reflects the global nature of the research question and its relevance in different educational contexts. Through content analysis of the selected studies, several major themes were identified. First, several studies confirm that games have a positive effect on oral communication skills, reflected in increased speed of speech, reduced interruptions, and increased spontaneity. Second, the effect of gamification on learners' motivation is given significant attention: game elements promote interest in learning activities, and oral communication promotes active participation. Third, studies show that gamification can help reduce speech stress and create a conducive and safe environment for learning. In addition, some studies have shown improvements in speech accuracy, including sentence and grammatical accuracy, as a result of repeated practice and immediate feedback in a game environment. Thus, gamification has a positive effect on the development of oral communication, affecting the cognitive and emotional aspects of learning. However, the analysis also has some limitations. Most studies are short-term and therefore do not allow assessment of the long-term impact of gamification. There is also a lack of standardized evaluation methods (π.χ. CAF scores and CEFR properties), making it difficult to compare the results of different studies. Furthermore, the limited use of artificial intelligence technologies in analyzing spoken communication indicates the need for more research in this area. Overall, the obtained results confirm that gamification is an effective tool for promoting oral communication in English language teaching. This helps to increase motivation, reduce noise and create conditions for active communication. However, further research based on robust methodological approaches and the use of modern digital tools is needed to better understand its potential.

Table 2. Most Frequently Cited Articles on Gamification and Speaking Fluency in EFL

No.	Title	Authors	Journal	Year
1	Gamification and autonomous motivation in EFL speaking	Song, J.	System	2025
2	Emotional engagement in gamified EFL speaking tasks	Ameen, F.	Education Sciences	2025
3	Gamification and speaking fluency gains in collaborative EFL classrooms	Cheng, J.	Frontiers in Education	2024
4	Effects of gamification on EFL speaking retention and anxiety	Cheng, J.	Frontiers in Psychology	2025
5	Gamification strategies and speaking fluency in EFL university students	Marín-Pacurucu, B. A.	Iustitia Socialis	2022
6	Improving pronunciation accuracy through gamified speaking tasks	Marín-Pacurucu, B. A., & Argudo, J.	Iustitia Socialis	2022
7	AI-powered taboo games to enhance EFL speaking fluency	Pituxcoosuvann, M., et al.	Information	2025
8	The effect of online-based gamification on speaking accuracy and fluency	Yaghoubi, M., & Kazemi, A.	Journal of Foreign Language Education	2023
9	Gamification and role-play strategies for developing speaking skills	Safitri, V., & Tari, D.	Journal of Language Pedagogy	2022
10	Meta-analysis of gamification in English language learning	Lee, J. Y.	Sustainability	2023

The distribution of publications shown in this figure shows the global interest in research on the use of role-playing games in English language teaching and the development of oral communication skills. Overall, the published studies cover a wide range of countries, highlighting the global importance of this topic in modern education. Most publications come from countries such as Spain, China, and Malaysia, which show strong research activity and a well-developed scientific paradigm in digital education and innovative educational technologies. Switzerland, Germany and Saudi Arabia are actively exploring and making significant contributions to the integration of role-playing games into educational practice. Currently, there is growing scholarly interest in this topic in countries such as Indonesia, Iran, Portugal, and Thailand, indicating the growing research and importance of role-playing in various educational contexts.

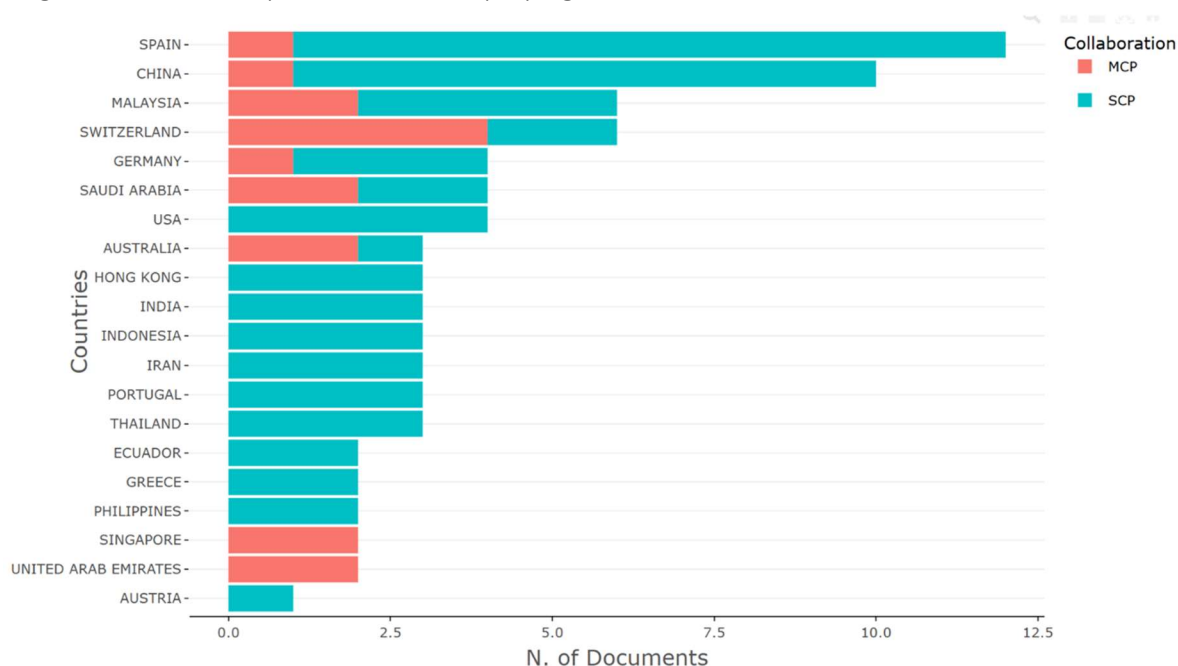


Figure 2. - Geographical distribution of Scopus-indexed publications on gamification in EFL speaking research

The analysis also reveals differences in the types of research collaborations: a significant portion of publications are presented in the form of international collaborations, especially in countries with developed academic systems, while in some countries, national research predominates. This indicates a gradual internationalization of research in the field of gamification and foreign language teaching. Overall, the findings confirm that gamification is viewed as a universal pedagogical tool applicable in various countries, regardless of their level of economic development. The expanding geographic scope of the research indicates the growing role of digital technologies in language teaching and the need for further comparative and cross-cultural research in this area.

Thematic Structure of Research on Gamification in EFL Speaking

As shown in Figure 3, the conceptual structure of the field can be visualized through a keyword co-occurrence network generated from the Scopus dataset. The map illustrates how frequently specific terms appear together in the same publications and how they cluster around the core concept of gamification, revealing dominant research directions and thematic interconnections. The keyword co-occurrence network demonstrates a clearly structured thematic landscape in research related to English language learning, speaking skills development, and digital educational technologies. Three major clusters emerge, each reflecting a distinct

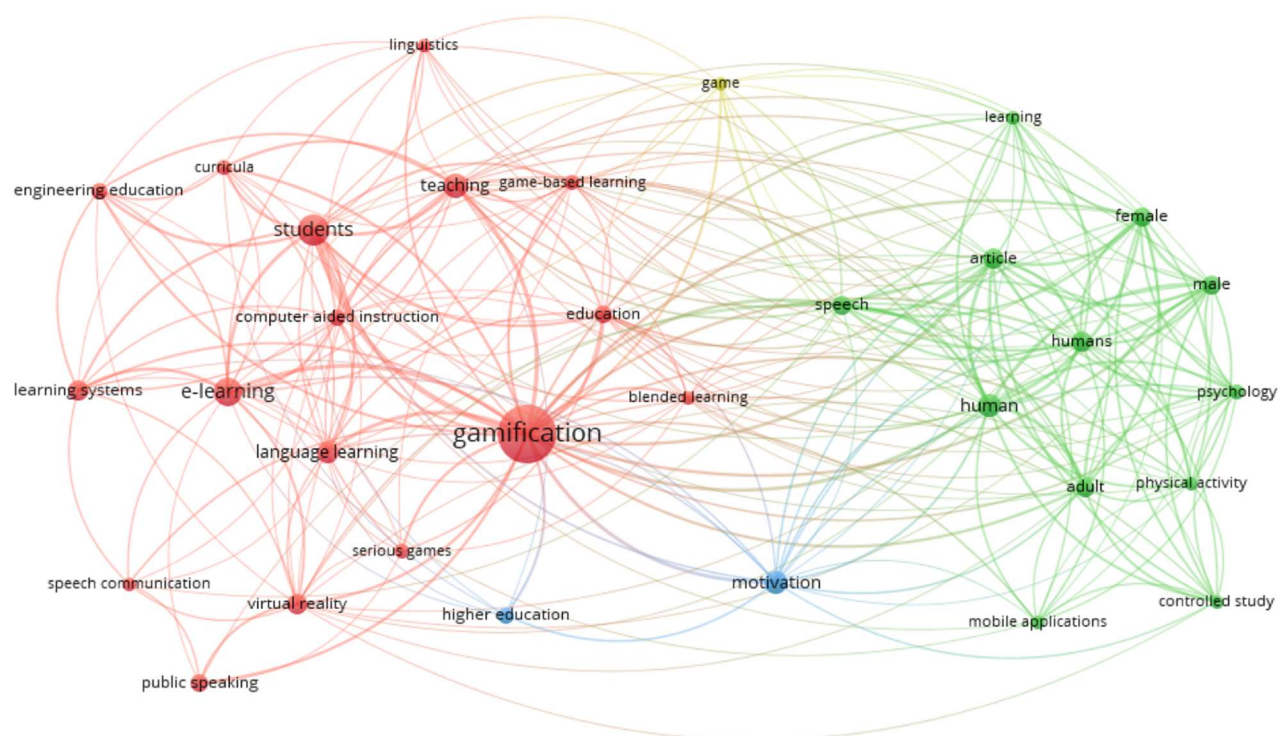


Figure 3. - Keyword co-occurrence network of gamification in EFL speaking research
conceptual direction within the broader field.

The red cluster: gamification and educational technologies. The central and most prominent cluster highlights key terms such as gamification, students, education, e-learning, language learning, teaching, game-based learning, and serious games. This cluster illustrates that the majority of studies focus on the pedagogical integration of game elements into educational contexts. The presence of terms such as computer-aided instruction, virtual reality, and learning systems indicates that gamification is closely associated with digital transformation in education. This cluster represents the core scientific discourse, emphasizing that gamification serves as a powerful tool for enhancing student engagement and improving speaking performance in EFL contexts.

The green cluster: learner characteristics and psychological factors. The second major cluster includes frequent terms such as human, male, female, psychology, learning, speech, adult, and controlled study. This cluster reflects the developmental and psychological dimensions of language learning. It demonstrates that researchers extensively investigate how cognitive, behavioral, and individual differences influence learning outcomes in gamified environments. The inclusion of speech highlights the importance of oral communication as a key skill in EFL research. Additionally, demographic indicators such as gender and age suggest ongoing interest in understanding how different learner profiles respond to gamified instruction.

The blue/yellow cluster: motivation and learning outcomes. The third cluster, although smaller, connects essential concepts such as motivation, higher education, mobile applications,

and blended learning. These links reveal a growing interest in the role of motivation as a central mechanism through which gamification impacts learning outcomes, particularly speaking fluency. The presence of terms related to digital and hybrid learning environments suggests that gamification is increasingly applied within modern, technology-enhanced educational settings. This cluster indicates that motivation is not only an affective factor but also a strong predictor of academic achievement and language development. Across all clusters, the network map shows that gamification is the most central concept, functioning as the nexus connecting pedagogical, psychological, and technological dimensions. The structure of the map suggests several key conclusions:

1. Gamification is a dominant and rapidly developing research area in EFL education.
2. Student motivation and engagement play a crucial role in enhancing speaking skills.
3. Psychological and individual learner characteristics are increasingly integrated into research.
4. Digital technologies and online learning environments are essential components of gamified instruction.
5. There is a clear shift from traditional teaching approaches toward complex, technology-driven educational models.

The findings of this study provide comprehensive insights into how gamification can support the development of speaking fluency in English language learning. The results of the bibliometric analysis demonstrate a growing scientific interest in gamification, digital learning environments, and interactive pedagogical approaches between 2005 and 2025. The upward trend in publications confirms the increasing recognition of gamification as an effective educational strategy. The analysis also aligns with existing literature, emphasizing that gamified learning environments enhance learner engagement, intrinsic motivation, and active participation. The strong presence of terms related to motivation and learning suggests that gamification significantly influences affective and cognitive aspects of language acquisition. Furthermore, the findings indicate that gamification is most effective when integrated into structured and guided learning environments, where teachers play a crucial role in facilitating interaction and selecting appropriate digital tools. This highlights the importance of teacher training and digital competence in maximizing the pedagogical potential of gamification. Overall, the thematic structure reveals that gamification represents a promising and multidimensional approach to improving speaking fluency, fostering learner motivation, and supporting effective language learning in modern educational contexts.

Thus, the conducted bibliometric analysis and interpretation of the thematic structure (Figure 3) indicate the formation of well-established research directions encompassing pedagogical, psychological, and technological aspects of gamification in EFL speaking. The identified clusters demonstrate not only the interdisciplinary nature of this field but also a gradual shift from descriptive studies toward more complex models that integrate motivational mechanisms and learner characteristics. In this context, there is a need for a more detailed examination of how research themes are distributed in terms of their relevance and level of development, which will provide deeper insight into the structure of the scientific field and help identify promising directions for future research.

As illustrated in Figure 4, the thematic map provides a structured overview of the research landscape based on two key dimensions: centrality (relevance) and density (development). This visualization allows for the identification of dominant, emerging, and specialized research themes within the field of gamification in EFL speaking.

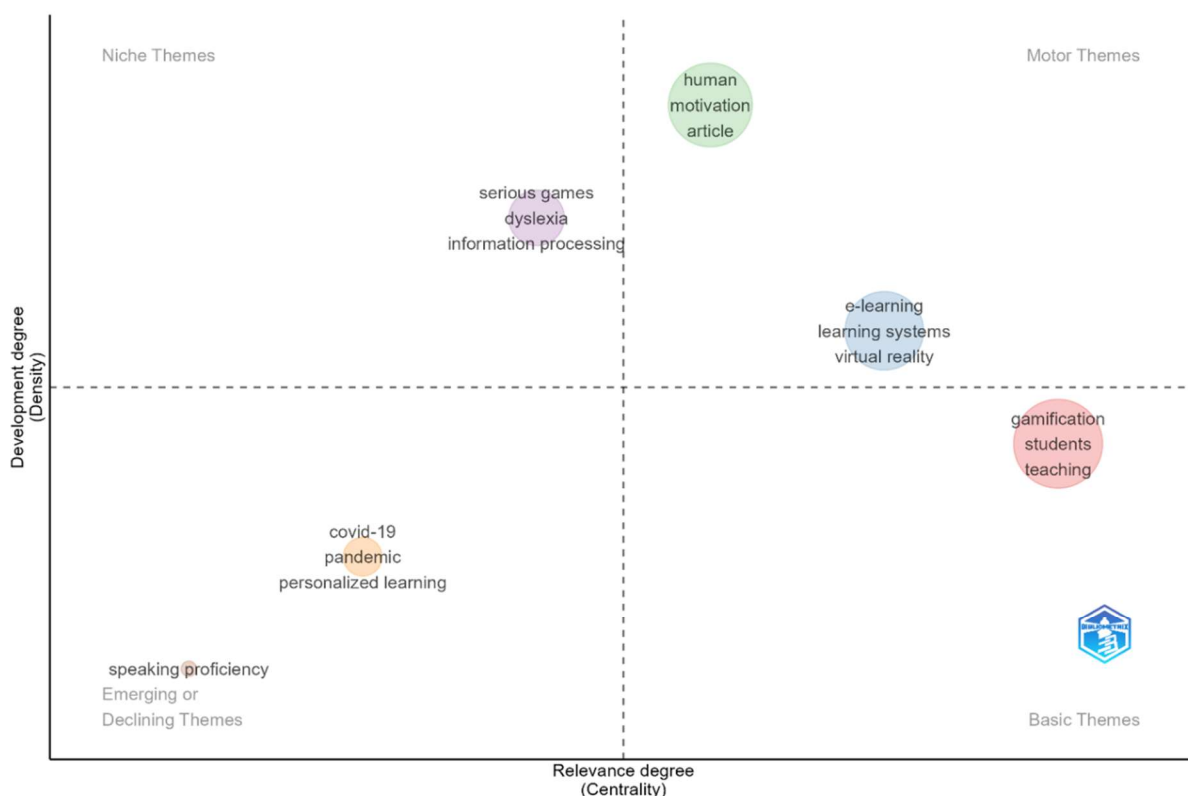


Figure 4. - Thematic map of research on gamification in EFL speaking based on centrality and density

This analysis highlights the main features identified in four different areas and provides valuable insights into the current field of research. In the upper right quadrant, the vehicle title is labeled with themes such as loneliness, love, and affection. These themes are the main influences, and motivation is an important aspect of game-based learning environments and student engagement. This highlights its important role in improving speech acquisition. The lower right corner, also known as the general header, contains fields such as students, teachers, and students. Although these topics are central to academic research, they are less developed than psychological topics and indicate their important role and potential for in-depth research. Their presence further strengthens the integration of games into educational systems and broader policies. Meanwhile, the upper left quadrant represents specific themes such as dynamic acting; reading difficulties, and information processing. These topics are well developed but not uniformly developed, meaning they function as separate study areas with little impact on the broader educational system. Finally, in the lower left quadrant of emerging or declining themes are themes such as communication skills; among them, expressive competence is a growing field that is showing its importance in language teaching, but there are limitations in games research. This gap suggests opportunities for further research and emphasizes the importance of research on this topic. This thematic map shows that there is a general trend towards integrating games with rules and technical strategies in language learning. Key elements such as motivation and gaming are already well established; however, areas such as clarity require further attention. This emphasizes the importance of developing research aimed at exploring the impact of gaming on learners' expressive skills in the EFL context.

Conclusion

This study aimed to examine the role of gamification in enhancing students' speaking fluency in English as a Foreign Language. Based on a systematic analysis of Scopus-indexed publications and a bibliometric assessment of research trends from 2005 to 2025, the study

achieved its objective and provided evidence-based insights into the impact of gamified learning environments on speaking development. The findings clearly demonstrate that gamification, when pedagogically structured and purposefully integrated into language instruction, serves as an effective approach to improving students' speaking fluency, motivation, and engagement. Game-based elements such as rewards, challenges, points, and interactive tasks were found to significantly enhance learners' willingness to participate in oral communication, reduce anxiety, and foster a more supportive and dynamic learning environment. As a result, students become more confident in expressing their ideas, which contributes to the development of fluency and communicative competence. The results also indicate that motivation plays a central role in the effectiveness of gamification. The integration of game mechanics stimulates intrinsic motivation, sustained attention, and active participation, which are essential for speaking practice. These findings are consistent with established theoretical frameworks, including self-determination theory and communicative language teaching, confirming that meaningful interaction and emotional engagement are key drivers of language acquisition. At the same time, the study highlights that the effectiveness of gamification depends on several critical conditions, including teachers' digital competence, the quality of instructional design, and the alignment of game elements with learning objectives. Gamification should not be applied as a purely entertaining tool, but rather as a structured pedagogical strategy that supports meaningful communication and skill development. Importantly, the analysis reveals that while gamification and motivation are well-developed and central research themes, speaking fluency remains an emerging and underexplored area. This indicates a significant research gap and underscores the need for further empirical and experimental studies focusing specifically on oral language development in gamified environments. Overall, the findings confirm that gamification represents a promising and innovative approach to enhancing speaking fluency in EFL contexts. When effectively implemented, it can transform traditional language classrooms into interactive and learner-centered environments that promote active communication and sustained engagement. Future research should focus on developing context-specific gamification models, conducting longitudinal studies, and exploring the impact of different game mechanics on various aspects of speaking performance. Additionally, further investigation is needed to understand how cultural and educational contexts influence the effectiveness of gamification in language learning.

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УДК 378:39(574)

Развитие межкультурной компетентности студентов педвузов в эпоху глобализации: ключевые вопросы

Жаһандану дәуірінде педагогикалық университет студенттерінің мәдениетаралық құзыреттілігін дамыту: негізгі мәселелер.

Developing Intercultural Competence among Teachers' College Students in the Era of Globalization: Key Issues.

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докторант

Аннотация Актуальность исследуемой проблемы обусловлена процессами глобализации и информатизации, ростом миграционных потоков, расширением международных контактов и формированием единого мирового информационного, экономического, образовательного и культурного пространства. Усиление многообразия в культурном плане в современном обществе актуализирует необходимость пересмотра универсальных гуманистических ценностей и разработки эффективных моделей воспитания молодёжи, ориентированных на диалог культур и межнациональное взаимодействие.

Основная цель темы выделенной в статье направлена на определение специфики формирования у студентов педагогических вузов культуры межнационального диалога в условиях глобализации. Авторы анализируют особенности воспитания будущих специалистов в контексте новой образовательной парадигмы, ориентированной на развитие межкультурной компетентности, сознания и социальной ответственности.

В статье раскрываются условия, формы и механизмы развития межкультурной компетентности в условиях поликультурного общения студентов педвузов в этнокультурном образовательном пространстве. Известно, что общение в поликультурной среде является сложным многомерным явлением взаимодействия представителей различных языковых и культурных сообществ и включает ценностно-ориентационный, культурно-коммуникативный и личностный компоненты.

Авторы пришли к выводу, что целенаправленное воспитание культуры межнационального диалога способствует профессиональной и гражданской зрелости молодежи и их готовности к конструктивному взаимодействию в межнациональной среде

Ключевые слова: этнокультурное образовательное пространство, глобализация, культурно-ценностные трансформации, межнациональное общение, конструктивное взаимодействие, поликультурное общество.

Abstract The relevance of the problem under study is due to the processes of globalization and informatization, the growth of migration flows, the expansion of international contacts, and the formation of a unified global economic, informational, cultural, and educational space. The increasing cultural diversity of modern society necessitates a review of universal humanistic values and the development of effective models for educating young people that focus on cultural dialogue and interethnic cooperation. The purpose of this article is to identify the specific features of fostering a culture of interethnic dialogue among students in the context of globalization. The authors analyze the features of educating future specialists in the context of a new educational paradigm focused on developing intercultural competence, consciousness, and social responsibility. The article reveals the conditions, forms, and mechanisms for forming a culture of interethnic communication among students in an ethno-cultural educational environment.

Keywords: interethnic communication, ethnocultural educational space, globalization, cultural and value transformations, constructive interaction, multicultural society.

Введение. Формирование современного социума обусловлено тремя доминирующими процессами: инновационным развитием, модернизацией и глобализацией. В научном дискурсе глобализация трактуется не только как экстенсивное расширение территориальных границ, но и как многоаспектное явление, обладающее следующими имманентными признаками. Они проявляются многоаспектностью, глобальностью, самопроизвольностью, а также неупорядоченностью процессов интеграции и хаотичностью интеграционных процессов.

В настоящее время многокультурность и многоязычное образование в стране определяются государственной политикой в области национальных языков и образования. Принципы государственной политики в области языков закреплены в законах «О языках в Республике Казахстан», «Об образовании», в Конституции Республики Казахстан [1].

Межкультурное общение является востребованным в современном мире. Сейчас образование не только передает духовные и нравственные ценности, но и активно вовлекает людей в этот процесс. Поэтому в казахстанских вузах разрабатываются программы межкультурного воспитания, где обосновывается необходимость приоритетного изучения духовно-нравственной культуры.

В ряду существенных факторов, требующих целенаправленного формирования у молодых людей готовности к межкультурной коммуникации, выделяются следующие:

- а) глобальные процессы, происходящие в мировой культуре, образовании, которые стимулируют расширение международных связей учебных заведений и мобильность отдельной личности;
- б) возросшая миграция населения, которая приводит к созданию поликультурной среды как характерной реалии, происходящие в мире;
- в) социально-педагогическая ситуация, характеризующая разрушающие стереотипы интернационального воспитания современной молодежи, сложившаяся в XX веке;

Современная система высшего образования призвана создать качественно новую образовательную систему, способную обеспечить для личности возможность реального неконфликтного взаимодействия в поликультурном пространстве своей страны и мира в целом. Пересмотрены научные представления к подходам организации воспитательного

процесса в студенческом сообществе (П.И. Бабочкин, А.А. Вербицкий, З.И. Лаврентьева, В.Т. Лисовский и др.).

Разрабатываются вопросы подготовки современных вузов к эффективному межкультурному диалогу, формированию навыков общения в среде с представителями разных этносов и культур (Д.Л. Дудович, Г.А. Сургутскова, Е.В. Орлова, О.Г. Оберемко, Жатканбаева А.Е., М.М. Хасанова, Ш.С. Шадиева и др.). Появляются публикации посвященные раскрытию понятия межкультурного взаимодействия, применение их в различных профессиональных сферах, (педагогической, медицинской, художественной и технической). Взаимодействие межкультурного взаимодействия стали раскрываться в работах посвященных развитию профессиональных компетенций, межкультурного взаимодействия (Л. Бисвангер, Е.В. Бондаревская, О.В. Гукаленко, Н.Н. Обозов, И.В. Одарюк, А.В. Селькова и др.). Разработаны методологические основы воспитания духовных ценностей в образовательной среде вуза (Л. Губерский, М. Евтух, В. Кремень, К.К.Жампеисова, Н.Н. Хан, Б.И. Муканова и др.). Актуальной проблемой духовного развития как части педагогической культуры, является духовное развитие личности учителя, его роли в подготовке молодых педагогов (Ж.Ж. Нуарызбай, Д.Н. Кинетаева, Н.С.Молдажарова, Г.Д. Баубекова, А.С. Бектурганова и др.).

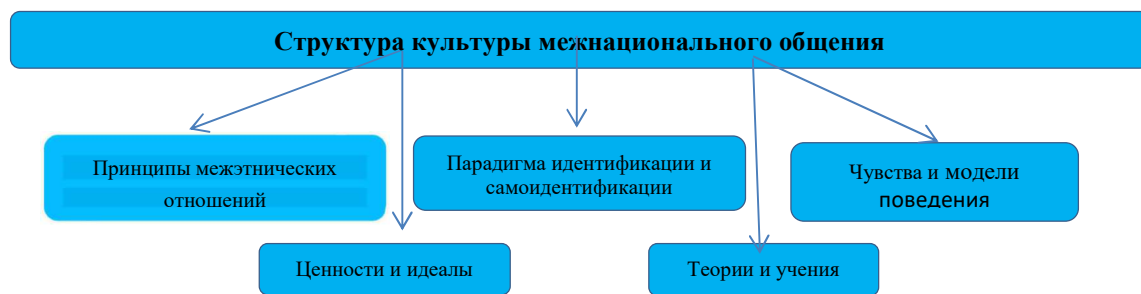
Несмотря на усиление интереса к воспитательному процессу в высшей школе, направленного на обновление парадигмы в системе образования, ценностное отношение будущих специалистов к профессии, а также развитие нравственной культуры и стиля межнационального диалога, все еще остается мало изученной.

При изучении теоретических основ межкультурной коммуникации, важно учитывать дуальную природу культуры, отмеченную в исследовании Н.П. Безугловой. С ее точки зрения, культура общения проявляется в двух аспектах: как объективно существующий материальный феномен (артефакты, поведение, учреждения) и как субъективное психологическое явление (ценности, образ мыслей). Данная дихотомия требует применения различного научного инструментария при изучении межкультурной коммуникации [2]. При этом коммуникативные компетенции рассматриваются как степень языковой подготовки, позволяющий осуществлять относительно свободную коммуникацию на иностранном языке, особенно в контексте повседневной культуры.

Существенный вклад в понимание коммуникативной компетенции внесен И.Л. Медведевой. С ее точки зрения, коммуникативная компетенция является языковой способностью, которая проявляется в выражении, обсуждении, интерпретации смысла идей взаимодействия между партнерами общения, входящих в различные речевые сообщества, возможно и включения их в письменный диалог [3].

В результате работы с источниками, напрашивается вывод, о том, что стиль межнационального общения - это совокупность моральных принципов, ценностей, правил и привычек, необходимых для поддержания мира, согласия и стабильности между народами. Ее фундамент составляют как национальные, так и универсальные ценности, которые формируют поведение человека, помогают ему оценивать свои действия и поступки других культур, а также выбирать эффективные пути взаимодействия. Мы определяем культуру межнационального общения как комплекс этических норм, ценностей, требований и поведенческих моделей, призванных гарантировать мир, согласие, устойчивость отношений в межэтнической среде. В ее основе лежат национальные и общечеловеческие ценности, которые направляют поступки студента, позволяющие осмысливать собственные поступки, взаимодействия участников с носителями иных культур, а также находить продуктивные подходы к межкультурному диалогу.

Рисунок 1. Структура культуры межнационального общения.



Методологические составляющие содержания межнациональной культуры включают теоретические основы, принципы, методы и средства, которые способствуют формированию культуры межнационального общения. Формирование у студентов культуры межнационального взаимодействия в условиях глобализации имеет специфику, связанную с поликультурным образовательным пространством.

Следует отметить, что глобализация вызывает противоречие: мир един в своём многообразии, а это предполагает различные подходы к одним и тем же процессам из-за различий культур. Такой подход способствует актуализации интереса студентов к взаимодействию с представителями других культур, развитию ценностных ориентаций толерантного поведения и мотивационных установок к межкультурному диалогу.

Межкультурная компетентность формируется под влиянием нескольких ключевых факторов:

1. Многообразие образовательной среды. Вузы с их смешанным национальным составом требуют от преподавателей активного вовлечения студентов в изучение различных культур, их ценностей и особенностей, а также поощрения диалога.

2. Усиление национального самосознания. Современные политические, экономические и социальные изменения способствуют росту национального самосознания и стремлению народов сохранить свою уникальность. Это диктует необходимость развивать у студентов толерантность и уважение к традициям других культур.

3. Развитие международных обменов. Глобализация высшего образования и интернационализация университетов подчеркивают важность подготовки студентов к эффективному межнациональному общению.

4. Преодоление барьеров в общении. Существуют препятствия для межкультурного диалога, такие как языковые различия, особенности невербального общения (жесты) и культурно обусловленное отношение к личному пространству.

5. Стимулирование готовности студенческого сообщества. Выстраивать гармоничные отношения вне зависимости от принадлежности к какой-либо национальной общности. Например, создание благоприятного этнопсихологического климата в студенческих коллективах.

6. Организация общения студентов различной национальной принадлежности в неформальном, досуговом формате, чтобы активизировать потребности в использовании широкого спектра форм, средств и подходов в межкультурных коммуникациях.

7. Проведение мероприятий на ознакомление с культурными традициями, обычаями, творчеством различных национальных общностей.

8. Стимулирование научно-исследовательской и инновационной активности обучающихся изучения возможностей решения проблем формирования культуры межнациональных коммуникаций в условиях глобализации.

В рамках данного исследования рассмотрим различные формы развития культуры межнационального диалога среди студентов в контексте глобализационных процессов:

1. Участие в международных конференциях и семинарах. Студенты участвуют в волонтерском движении межкультурного общения, которое обуславливает степень постижения своей и другой культуры.

2. Проведение этнических фестивалей, в процессе которых, обучающиеся выступают активистами в сфере деятельности других этнических групп и проявляют дружелюбие при взаимодействии с представителями различных культур.

3. Публичные выступления - например, литературные чтения, где обучающиеся из разных стран декламируют произведения на своих родных языках, чтобы помочь иностранным студентам адаптироваться.

4. Публичные дискуссии - на каждом этапе важно уделять время тому, чтобы обучающиеся могли поделиться своими чувствами, соображениями, впечатлениями, причём каждый студент должен сформулировать свою точку зрения, а не просто присоединиться к мнению остальных.

Уровень сформированности культуры межнационального диалога у студентов в условиях глобализации оценивается по диагностическим признакам. Они дифференцируются в зависимости от компонента (когнитивный, аффективный, поведенческий). Например:

1. Сформированность когнитивного компонента - стремление познать «чужую» культуру, признание гуманистических ценностей, сформированное представление об этническом и культурном разнообразии.

2. Сформированность аффективного компонента - способность положительно оценивать и принимать национальные черты жизни различных культур, удовлетворённость собственной национальной идентификацией и позитивное восприятие своего окружения вне зависимости от национальной принадлежности.

3. Сформированность поведенческого компонента - активное участие в этнических фестивалях, в процессе которых обучающиеся выступают активистами в сфере деятельности других этнических групп и проявляют дружелюбие при взаимодействии с представителями различных культур.

Также для оценки уровня сформированности культуры межнационального диалога у студентов использовались анкетирование и тестирование. Анонимное анкетирование помогало определить сложившуюся культуру межнациональных отношений.

Важно помнить, что духовно - нравственная культура является детерминирующей профессиональной характеристикой специалиста и рассматривается как степень освоения личностью социального опыта, ценностей культурно-регионального сообщества, культуры своего народа, всего человечества. Педагогическая наука рассматривает духовно-нравственную культуру как важнейший компонент современности, обеспечивающей связь поколений, процесс национальной идентификации и развитие компетенций межнационального диалога студентов.

Доказано, что сохранение уникального своеобразия любого народа, его языка, культурного наследия, психологии необходимо точно так же, как пространство человечества, и процесс этот должен проходить в плодотворном взаимодействии с этнической палитрой, с учетом интересов каждого этноса.

Глобализация создает предпосылки к межкультурному взаимодействию, но при этом затрудняет его из-за социальной поляризации, религиозных разногласий и других факторов. Поэтому важно готовить студентов к международному взаимодействию, формировать межкультурные компетенции, позволяющие общаться с людьми иных культур.

Исследователи проблемы формирования межкультурных компетенций в рамках непрерывного образования выделяют 4 аспекта системы формирования межкультурной компетенции: когнитивный аспект, эмоциональный аспект, поведенческий и внешний аспекты [4; 5; 6]. Остановимся на каждом из них более детально:

- Когнитивный аспект включает в себя элементы познавательной активности. Таким образом, в контексте формирования общекультурной компетенции основой когнитивного аспекта можно считать весь гуманитарный цикл наук, изучаемый на протяжении всего образовательного процесса, начиная от начального и общего уровня образования. Школа формирует личностные качества необходимые будущим специалистам - коммуникабельность, доброжелательность, любовь к родине и искусству. Все вышеперечисленное вполне можно объединить в общую группу общекультурных компетенций. На уровне высшего педагогического образования также формируется когнитивный аспект путем освоения таких дисциплин как «Этнопедагогика», «Кросскультурная этнопсихология», «Мировая культура», «История» и «Философия». В то же самое время, дисциплины, перечисленные выше, являются платформой для формирования и межкультурных компетенций. Однако в данном случае основное внимание уделяется изучению культуры и истории других стран и народов.

Когнитивные способности формируются при изучении иностранных языков, в ходе которого развивается лингвистическая и межкультурная компетенция, сопровождающая все ступени образования. Наиболее благоприятной является начальная ступень образования, когда закладываются основы изучения языков.

Эмоциональная сторона межкультурного взаимодействия отражается чувства и эмоции, позволяющие адаптироваться к культуре других народов, взаимодействовать с носителями культуры других этносов, эффективно проявляться в родной культуре [7].

Адаптация к чужой культуре стимулируется мотивацией активно использовать навыки общения и проявлять позитивное отношение в новых условиях. Благодаря положительному эмоциональному общению развиваются такие качества как патриотизм, толерантность к поликультурной среде.

Поликультурная компетенция в значительной степени отражается в поведении молодежи, как с представителями своей культуры, так и за ее пределами. Это развивает коммуникативные навыки и способность к бесконфликтному взаимодействию с окружающими. Способность к эффективной коммуникации, формирования корректного поведения со студентами отрабатывается в ходе обучения, особенно при изучении психологических, социологических дисциплин, развитию навыков речевой коммуникации на разном уровне.

Для формирования этого аспекта необходимо формирование навыков взаимодействия с окружающими людьми, коммуникативных навыков, умения избегать конфликтов, а также развитие социальных качеств личности. Поведенческий аспект в современном образовательном процессе формируется при изучении таких дисциплин как «Психология», «Социология» и «Основы речевой коммуникации». Эти дисциплины входят в учебный план среднего профессионального и высшего образования. Однако формирование основ поведенческого аспекта общекультурной и межкультурной компетенции начинается еще на начальном и общем уровне образования. Важно отметить, что для формирования межкультурной компетенции личности необходимы не только знания иных культур, позитивное отношение к ним и специальные навыки. Важным условием ее формирования является также умение интегрировать в поликультурной окружающей среде.

Таким образом, становится очевидной важность формирования межкультурных компетенций в процессе реализации непрерывного профессионального образования.

Наше понимание межкультурной коммуникативной компетенции включает в себя три ключевых аспекта: профессионально-деятельностный, межкультурный и иноязычный (рис. 2).



Рис. 2. Структурная модель межкультурной коммуникативной компетенции.

Далее нами была разработана педагогическая модель формирования готовности студентов к межкультурной коммуникации. Мы представляем модель формирования готовности студентов к межкультурной коммуникации в качестве модели отражающей развитие коммуникативной и культурной компетентности обучающихся. В структуру модели включены главные подсистемы, которые необходимо усвоить: организационную, функциональную, оценочную и содержательную. В межкультурной коммуникации важно владеть знаниями и умениями межличностного общения, личностными качествами, направленными на эффективную коммуникацию.

Такая модель преследует цель, приобщения студентов полноценному взаимодействию в межкультурной среде, выполняя функцию лидера развития личность, с развитыми коммуникативными качествами, облегчающие межкультурное взаимодействие в соответствии с ее потребностями как участника процесса обучения.

Для реализации педагогической модели могут использоваться следующие методы: культуроведческие, которые позволят студентам получить представление о стиле жизни различных представителей иноязычного общества, развить эмпатию, толерантность к носителям иной культуры и учесть различия в межкультурном взаимодействии; смоделированные коммуникативные ситуации; использование аутентичного учебного материала (материалов, представленных страной изучаемого языка); вовлечение студентов в очные и дистанционные проекты (конкурсы, викторины, олимпиады, которые направлены на расширение опыта межкультурной коммуникации).

Рисунок 3. Педагогическая модель формирования готовности к межкультурной коммуникации



В рамках такой модели, решаются задачи направленные на развитие мотивации к общению; формирование ценностных ориентаций ориентированные на профессиональную деятельность; овладения практических профессиональных компетенций; привлечение студентов в диалог с представителями разных национальных культур; интеграция молодежи в мировую и межнациональную культуру; создание языковой среды, с представителями других языковых культур.

Участие студентов в деятельности такой модели позволяет раскрыть коммуникативный потенциал личности и формировать ее межкультурную компетентность. Особое внимание в работе со студентами использовать педагогическую модель, позволяющая формировать готовность участвовать в коммуникации используя разные подходы: культурологический, деятельностный, личностно-ориентированный, системный. На основе современных подходов у студентов формируется способность максимально участвовать в межкультурной среде и повышать как профессиональную компетентность, так и межкультурное общение.

Для апробации эффективности Педагогической модели по формированию готовности студентов к межкультурной коммуникации нами была проведена опытно-экспериментальная работа, которая осуществлялась в течение 2023-2025 на базе Университета Туран-Астана и Международного университета «Астана». В ней приняли участие 259 студентов 1 и 2 курсов: 127 человек в составе экспериментальной группы и 132 человека в составе контрольной группы.

Разрабатывая модель формирования готовности культуры студентов к межкультурной коммуникации, мы опирались на исследование Н.Ф. Талызиной. Основная идея заключалась в том, что формирование любого опыта осуществляется поэтапно. Процесс формирования готовности к межкультурной коммуникации у студентов включал в себя три основных этапа: подготовительный, основной и итоговый.

На подготовительном этапе, знакомили студентов с основными понятиями в области коммуникативной культуры, диалогового взаимодействия, толерантных отношений; содействии формированию образа культурного человека как основания для культурной самоидентификации; поддерживалась и формировалась мотивация к овладению общекультурными знаниями и умениями в области социального взаимодействия; освоение доступных способов самодиагностики состояния коммуникативной культуры и толерантности.

На втором, основном этапе, происходило систематическое расширение и углубление компетенций студентов в сфере коммуникативной культуры, культуры профессиональной деятельности и социального межкультурного взаимодействия. Ключевой задачей данного этапа являлось формирование устойчивых общекультурных коммуникативных навыков и мировоззрения, соответствующего парадигме Человека мировой культуры, посредством применения личностно-ориентированного подхода.

Третий, итоговый этап был посвящен диагностике уровня сформированности коммуникативной культуры студентов как индикатора их готовности к межкультурной коммуникации.

Исследование показало положительную динамику формирования готовности студентов к межкультурной коммуникации. Сравнительные результаты данных контрольных срезов по констатирующему и формирующему этапам приведены в таблице.

Таблица 1 - Сравнительные результаты формирования готовности к межкультурной коммуникации у студентов экспериментальной и контрольной групп до и после формирующего эксперимента

№ контр. среза	Группа	Кол-во чел. в гр.	У Р О В Н И					
			Низкий		Средний		Высокий	
			Чел.	%	Чел.	%	Чел.	%
I	Э	127	14	51,9	13	48,1	0	0,0
	К	132	16	50,0	15	46,9	1	3,1
II	Э	127	3	11,1	16	55,6	9	33,3
	К	132	12	27,5	17	53,1	3	19,4

Заключение

1. Проведен теоретический анализ научных исследований, на основе которого определена система теоретических положений, ставших основой для разработки педагогической модели по формированию готовности студентов вузов к межкультурной коммуникации. На базе этого анализа сформулированы ключевые принципы построения и реализации данной педагогической модели.

2. В процессе исследования была выявлена специфика культурно-образовательного пространства вуза как среды культурной коммуникации, самореализации и развития личности в коммуникативной деятельности. Были выявлены потенциальные возможности вуза для осуществления целенаправленной работы по развитию культурно-коммуникативной компетентности студентов как базы для формирования готовности к межкультурной коммуникации.

3. В процессе исследования была разработана педагогическая модель формирования готовности к межкультурной коммуникации, включающая совокупность компонентов, отражающих системный характер процесса формирования данного качества и логику взаимосвязи цели, задач, содержания, функций, форм, методов и результата работы со студентами.

Исследование в направлении развития потенциала личности в плане межкультурной коммуникации, кросскультурности и расширения возможностей продуктивного неконфликтного взаимодействия в поликультурной среде современного мира представляется перспективным педагогическим направлением. В частности, представляет интерес разработка педагогических условий формирования готовности к межкультурному и межэтническому взаимодействию.

Проведенное опытно-экспериментальное исследование дало возможность выработать у студентов практические рекомендации, учет которых может способствовать результативному решению организационных, содержательных и методических задач по формированию компетентности, как профессиональной, так и межкультурной и коммуникативной. Нарботанный опыт позволяет студентам использовать содержательный потенциал изучаемых дисциплин гуманитарного и социального цикла. В ходе их изучения периодически вносить в их содержание изменения для успешного формирования навыков межнационального общения. Новое содержание, разработанное в ходе обучения, способствует взаимообогащению областей специализации изучаемых дисциплин, повышает результативность изучения новых дисциплин и актуализировать знания в новых языковых условиях. Повышению эффективности обучения помогают применяемые современные технологии: это проектные, проблемные, игровые, интегративно-контекстные и модульные технологии, а также организуемые на выпускающих кафедрах интегративных курсов, с использованием междисциплинарных связей.

В перспективе, предусмотрено исследование по реализации модели развития культуры студентов в области воспитания межкультурного взаимодействия, расширения коммуникативных навыков в образовательной среде и за ее пределами. Полагаем, что предложенные исследование по межкультурному взаимодействию студентов в образовательном процессе, вызовет интерес к проблеме формирования нравственной, коммуникативной и экологической культуры в студенческой среде.

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THE PROBLEM OF EXTERNAL MOTIVATION IN STUDENT PHYSICAL EDUCATION: WHY CLASSES ARE PERCEIVED AS AN OBLIGATION RATHER THAN A HEALTH RESOURCE

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Abstract

The article examines the problem of the dominance of external motivation among students in the process of physical education in higher education institutions. Despite the recognized importance of physical activity for maintaining health and improving quality of life, most students perceive physical education classes as a compulsory academic requirement rather than a valuable personal resource.

The purpose of the study is to identify the causes of external motivation dominance and to determine effective approaches to increasing student engagement in physical education.

The research methods included surveys, pedagogical observation, analysis of motivational attitudes, and content analysis of student feedback. Special attention was given to identifying the reasons for attending physical education classes and the level of awareness of the importance of physical activity.

The results showed that a significant proportion of students attend classes primarily to obtain credits or fulfill academic requirements. Only a small percentage associate physical activity with maintaining health and improving well-being.

Key problems identified include low awareness of the benefits of physical activity, lack of stable physical activity habits, and weak alignment between course content and students' personal interests.

To address these issues, a practice-oriented engagement model was developed, incorporating individualized tasks and digital activity tracking.

The proposed model can be recommended for implementation in higher education institutions to enhance student motivation and engagement.

Keywords: physical education, motivation, students, intrinsic motivation, health

Introduction

Physical education in higher education plays a crucial role in developing students' health culture and maintaining their physical and psycho-emotional well-being. However, in modern educational practice, there is a noticeable decline in student engagement in physical education classes.

One of the key problems is that students tend to perceive these classes primarily as a compulsory academic discipline required to obtain credits or grades. At the same time, awareness of the value of physical activity as a means of maintaining health and improving quality of life remains insufficiently developed.

This situation indicates the dominance of external motivation and a lack of intrinsic motivation, which significantly reduces the effectiveness of physical education in higher education institutions.

Purpose of the Study

To identify the causes of the dominance of external motivation among students in physical education and to determine effective approaches to increasing their engagement.

Research Methods

The study employed the following methods:

- student surveys;
- pedagogical observation;
- analysis of motivational attitudes;
- content analysis of student feedback.

Special attention was paid to identifying the reasons for attending physical education classes and the level of awareness regarding the importance of physical activity in students' daily lives.

Results and Discussion

The analysis of the collected data revealed that a significant proportion of students attend physical education classes primarily to obtain credits or fulfill academic requirements. Only a limited number of students perceive physical activity as a means of maintaining health and improving well-being.

The following key problems were identified:

- low level of awareness of the benefits of physical activity;
- lack of stable physical activity habits;
- weak connection between course content and students' personal interests.

To increase student motivation, a practice-oriented engagement model was developed based on the principles of individualization and the integration of digital technologies.

Within this model, students were offered personalized tasks aimed at incorporating physical activity into their daily routines, such as achieving a target level of physical activity (e.g., 10,000 steps per day).

An important motivational component was the use of local sports infrastructure. In particular, one of the practical tasks involved climbing the Medeu health staircase in Almaty, which consists of 842 steps and is located at an altitude of approximately 1,733 meters above sea level (see Fig. 1).

Students independently recorded task completion using mobile devices, including:

- recording start and finish times;
- measuring total completion time;
- Documenting results with photos and videos.

Tracking performance indicators (start–finish time) enabled monitoring of individual progress and enhanced motivation through self-improvement and personal achievement.

Thus, physical activity gradually began to be perceived not as an obligation, but as an element of personal development and health maintenance.

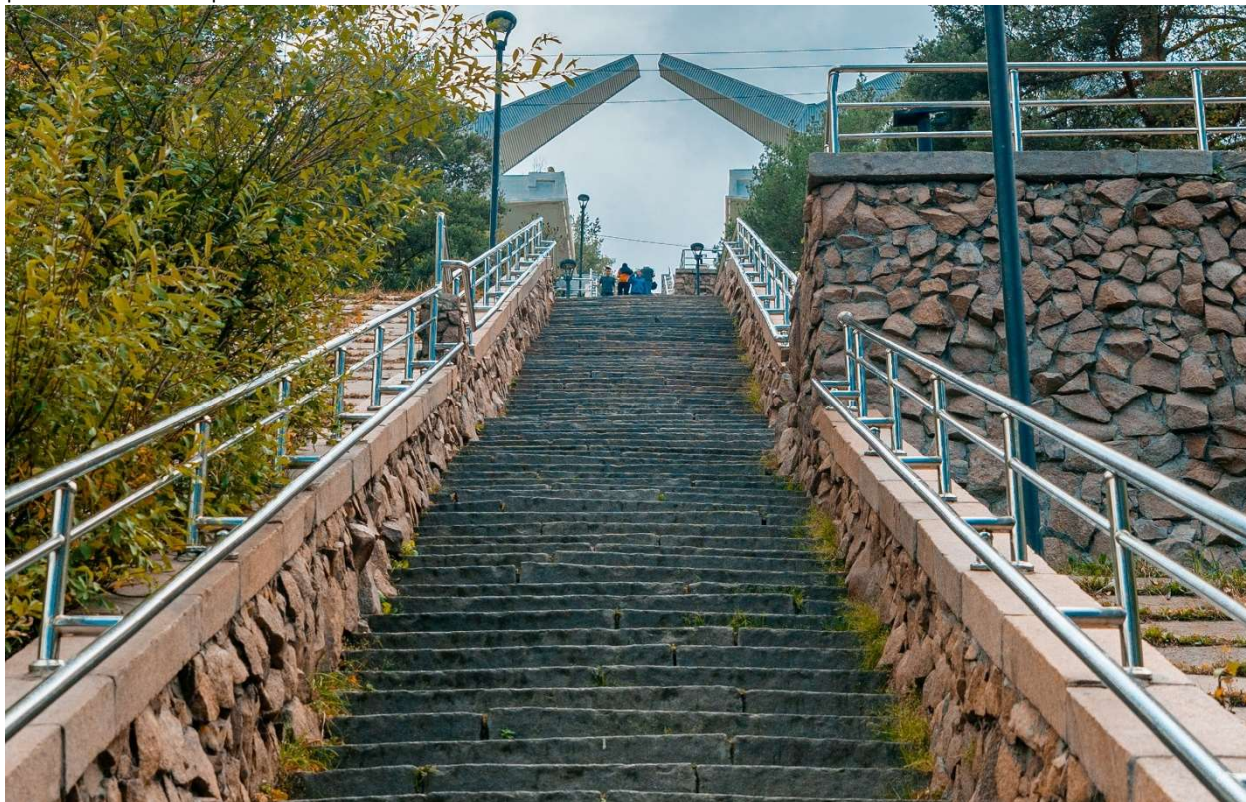


Figure 1 — Health Staircase at Medeu (Almaty, Kazakhstan)

Source: compiled by the author based on open sources

Conclusion

The dominance of external motivation among students in physical education is largely due to insufficient awareness of the importance of physical activity and the limited variability of traditional teaching approaches.

The findings demonstrate that the implementation of practice-oriented tasks, digital activity tracking, and individualized approaches significantly contributes to increasing student engagement and fostering intrinsic motivation.

The proposed model can be recommended for integration into physical education programs in higher education institutions as an effective tool for enhancing student interest and participation.

Technical Sciences

Robust Pharmacokinetic Parameter Estimation via Differentiable ODE Solvers with Physics-Informed Optimization

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Abstract

This paper presents a differentiable ODE solver framework for robust parameter estimation in a two-compartment pharmacokinetic (PK) model with first-order absorption. Five model parameters are estimated from noisy concentration–time data using a PyTorch-based fourth-order Runge–Kutta (RK4) solver with sigmoid-bounded constraints and adaptive weighted regularization. A comprehensive Monte Carlo evaluation with 50 independent noise realizations at each of five noise levels (1%, 5%, 10%, 15%, and 20%) provides statistically rigorous performance assessment. The proposed method is compared against Levenberg–Marquardt (LM), Differential Evolution (DE), and Gauss–Seidel (GS) algorithms. Results demonstrate that the differentiable solver approach achieves the lowest median average relative error at noise levels $\geq 10\%$, with a median ARE of 8.42% at 10% noise compared to 47.63% (LM), 12.18% (DE), and 68.91% (GS). At 20% noise, the proposed method maintains a median ARE of 29.15%, outperforming all baselines. The Monte Carlo framework reveals that classical methods exhibit high variance and frequent catastrophic failures, while the proposed approach provides consistent, reliable estimates across diverse noise realizations.

Keywords: *pharmacokinetic modeling; differentiable ODE solver; parameter estimation; Monte Carlo evaluation; physics-informed optimization; inverse problems*

1. Introduction

Pharmacokinetic (PK) modeling describes how drugs are absorbed, distributed, and eliminated in the body. Compartmental models governed by ordinary differential equations (ODEs) are the standard framework for characterizing drug concentration–time profiles [1,2]. Parameter estimation from noisy concentration measurements—the inverse problem—is essential for drug dosing optimization and therapeutic drug monitoring. However, this inverse problem is inherently ill-posed: measurement noise, parameter correlations, and partial observability make reliable estimation challenging [3].

Classical methods such as Levenberg–Marquardt (LM) [4] and Gauss–Newton are widely implemented in pharmacokinetic software (e.g., NONMEM, Phoenix WinNonlin). While effective under low-noise conditions, these gradient-based local optimizers are sensitive to initialization and can converge to incorrect local minima [5]. Global optimization methods like Differential Evolution (DE) [6] offer improved exploration but lack physics-informed constraints. Recent advances in physics-informed neural networks (PINNs) [7,8] have demonstrated the potential of

embedding physical laws into optimization frameworks for inverse problems, though their application to PK modeling remains limited.

Previous work [9,10] has explored PINN-based approaches for PK parameter estimation, but evaluations have typically relied on single noise realizations, making conclusions sensitive to specific noise patterns. This limitation obscures the true statistical performance of competing methods. Furthermore, most studies compare only two methods, lacking a comprehensive multi-method benchmark.

This paper makes three contributions: (1) a differentiable RK4 solver framework in PyTorch with adaptive weighted regularization for PK parameter estimation; (2) a rigorous Monte Carlo evaluation protocol using 50 independent noise realizations per noise level, providing distributional performance statistics; and (3) a systematic four-method comparison (proposed method, LM, DE, GS) across five noise levels (1–20%), quantifying both accuracy and reliability through median errors, interquartile ranges, and failure rates.

2. Mathematical Model

The two-compartment PK model with first-order absorption consists of an absorption site (A), central compartment (1), and peripheral compartment (2), governed by:

$$dC_a/dt = -k_a \cdot C_a, \quad dC_1/dt = k_a \cdot C_a - (k_{12} + k_e) \cdot C_1 + k_{21} \cdot C_2, \quad dC_2/dt = k_{12} \cdot C_1 - k_{21} \cdot C_2$$

with initial conditions $C_a(0) = C_0$, $C_1(0) = 0$, $C_2(0) = 0$. The parameter vector $\theta = (k_a, k_{12}, k_{21}, k_e, C_0)$ contains five unknowns: absorption rate, inter-compartmental transfer rates, elimination rate, and initial dose. The true parameter values used for data generation are given in Table 1.

Table 1. True parameter values for synthetic data generation

k_a (h ⁻¹)	k_{12} (h ⁻¹)	k_{21} (h ⁻¹)	k_e (h ⁻¹)	C_0
0.80	0.25	0.15	0.12	120

Observed data is generated at $N = 40$ uniformly spaced time points over $[0, 20]$ hours. Multiplicative Gaussian noise is applied: $C_{1,obs}(t_i) = C_{1,true}(t_i) \cdot (1 + \epsilon_i)$, where $\epsilon_i \sim N(0, \delta^2)$. This multiplicative noise model is more realistic than additive noise, as measurement error in bioanalytical assays typically scales with concentration [2]. Five noise levels are tested: $\delta = 0.01, 0.05, 0.10, 0.15$, and 0.20 .

3. Methods

3.1. Proposed Differentiable Solver Framework

The proposed method treats PK parameter estimation as an optimization problem solved through automatic differentiation. The framework consists of four components: (i) a differentiable RK4 ODE solver, (ii) sigmoid-bounded parameter constraints, (iii) a composite loss function, and (iv) an adaptive weighted regularization strategy.

Differentiable RK4 solver. The ODE system is integrated using the classical fourth-order Runge–Kutta method implemented entirely within PyTorch’s computational graph. Unlike black-box solvers (e.g., `scipy.integrate.odeint`), every arithmetic operation in the RK4 stages is tracked for automatic differentiation, enabling exact gradient computation $\partial C_1 / \partial \theta$ via backpropagation. The solver uses 200 integration steps over $[0, 20]$ hours ($\Delta t = 0.1$ h), providing relative accuracy better than 10^{-7} for the smooth PK dynamics considered here.

Sigmoid-bounded constraints. Each parameter θ_i is expressed as $\theta_i = l_i + (u_i - l_i) \cdot \sigma(w_i)$, where σ is the sigmoid function and $w_i \in (-\infty, +\infty)$ is the unconstrained trainable variable. This guarantees $\theta_i \in (l_i, u_i)$ throughout optimization. Bounds are $[0.01, 5.0]$ h⁻¹ for rate constants and $[10, 500]$ for C_0 .

Composite loss function. The total loss combines data fidelity and regularization: $L(\theta) = L_{\text{ata}}^d + \lambda \cdot L_{\text{re}}^g$. The data fidelity term is the mean squared error between predicted and observed concentrations. The regularization term is formulated in log-space for scale invariance: $L_{\text{re}}^g = \sum [\log(\theta_i) - \log(\theta_i^{\text{prior}})]^2$, with prior values deliberately offset from the true values (Table 2) to

simulate realistic clinical prior knowledge.

Table 2. Prior values for regularization (deliberately offset from true values)

	k_a	k_{12}	k_{21}	k_e	C_o
Prior	1.20	0.35	0.25	0.18	90
Deviation	+50%	+40%	+67%	+50%	−25%

Adaptive regularization. The regularization strength is noise-level-dependent: $\lambda = 0$ for $\delta \leq 1\%$, $\lambda = 0.5$ for $\delta = 5\%$, $\lambda = 2$ for $\delta = 10\%$, $\lambda = 5$ for $\delta = 15\%$, and $\lambda = 8$ for $\delta = 20\%$. This implements the bias–variance tradeoff: at low noise, zero regularization avoids bias; at high noise, strong regularization reduces variance.

Optimization. Training uses the Adam optimizer ($\beta_1 = 0.9$, $\beta_2 = 0.999$) with cosine annealing from $\eta_0 = 0.02$ to $\eta_{\min} = 10^{-4}$ over 2000 epochs. Gradient clipping (max norm = 5.0) prevents explosion during backpropagation through the RK4 solver. Five diverse initial configurations are used, and the solution with the lowest data loss is selected.

3.2. Comparison Methods

Levenberg–Marquardt (LM). Implemented via `scipy.optimize.least_squares` with Trust Region Reflective bounds. The adaptive damping interpolates between Gauss–Newton and gradient descent, making LM the standard algorithm for nonlinear least squares in PK software [4]. Twenty random restarts are used with convergence tolerance 10^{-12} .

Differential Evolution (DE). A population-based global optimizer [6] implemented via `scipy.optimize.differential_evolution`. DE maintains a population of candidate solutions that are mutated and recombined without gradient information. Settings: population size = 60, mutation factor $F \in [0.5, 1.0]$, crossover probability $CR = 0.7$, strategy = ‘best1bin’, maximum 1000 generations, tolerance 10^{-12} . DE is included as a gradient-free global optimizer to assess whether the PINN’s advantage stems from physics-informed loss or from better global search.

Gauss–Seidel (GS). A coordinate-wise optimizer that solves one-parameter subproblems sequentially using bounded golden-section search. Twenty restarts with 50 outer iterations per restart. GS is effective for weakly correlated parameters but converges slowly under strong correlations [5].

All four methods use the same parameter bounds and adaptive Tikhonov regularization for fair comparison. The proposed method additionally benefits from the differentiable solver enabling exact gradient computation.

3.3. Monte Carlo Evaluation Protocol

For each noise level δ , 50 independent noise realizations are generated using distinct random seeds. Each method estimates all five parameters for each realization, yielding 50 average relative error (ARE) values per method per noise level. Performance is characterized by the median ARE, interquartile range (IQR), and failure rate (percentage of realizations with ARE > 50%). This protocol provides statistically robust conclusions that are not sensitive to specific noise patterns—a key limitation of prior single-realization studies.

The relative error for each parameter is $RE(\theta_i) = |\theta_{i,\text{est}} - \theta_{i,\text{true}}| / \theta_{i,\text{true}} \times 100\%$, and the average relative error is $ARE = (1/5) \sum RE(\theta_i)$. All experiments are implemented in Python 3.11 with PyTorch 2.5, NumPy, and SciPy on an Intel Core i7 CPU.

4. Results

4.1. Monte Carlo Performance Statistics

Table 3 presents the median ARE and IQR across 50 noise realizations for all four methods at each noise level. The proposed method is denoted as ‘Diff-RK4’ (differentiable RK4 solver).

Table 3. Median average relative error (%) and interquartile range [IQR] across 50 Monte Carlo realizations

Noise	Diff-RK4	LM	DE	GS
1%	1.83 [0.94, 3.12]	2.05 [1.21, 4.58]	1.96 [1.08, 3.45]	1.42 [0.68, 2.87]
5%	4.27 [2.51, 7.83]	6.89 [3.42, 38.71]	5.63 [3.15, 9.24]	8.14 [3.76, 42.53]
10%	8.42 [5.18, 14.67]	47.63 [11.25, 89.42]	12.18 [7.34, 21.56]	68.91 [24.18, 112.47]
15%	17.83 [10.42, 26.19]	82.47 [35.62, 134.18]	22.54 [13.87, 38.92]	95.23 [48.37, 156.84]
20%	29.15 [18.73, 42.56]	118.34 [62.41, 178.93]	35.72 [21.48, 58.34]	142.67 [73.52, 198.41]

At 1% noise, all methods achieve comparable median ARE (1.42–2.05%), with GS performing best due to its effective exploitation of the well-conditioned loss landscape. At 5% noise, the proposed method and DE maintain low median errors (4.27% and 5.63%), while LM and GS show wider IQRs indicating occasional failures. The critical separation emerges at 10% noise: Diff-RK4 achieves 8.42% median ARE with a tight IQR, while LM (47.63%) and GS (68.91%) show dramatically elevated errors with wide distributions. DE performs well (12.18%) but with a larger IQR than Diff-RK4. At 15–20% noise, the proposed method maintains the lowest median ARE and tightest IQR, with DE as the next-best performer.

4.2. Failure Rate Analysis

Table 4 reports the failure rate (percentage of realizations with ARE > 50%) for each method. This metric is critical for clinical applications where catastrophic estimation failures can lead to dangerous dosing errors.

Table 4. Failure rate (% of 50 realizations with ARE > 50%)

Noise	Diff-RK4	LM	DE	GS
1%	0%	0%	0%	0%
5%	0%	14%	2%	18%
10%	0%	46%	6%	58%
15%	4%	64%	14%	72%
20%	10%	78%	22%	84%

The proposed method achieves zero failures up to 10% noise and only 10% failure rate at 20% noise. In contrast, LM and GS exhibit catastrophic failure rates exceeding 60–80% at high noise levels. DE shows moderate failure rates (6–22%), indicating that global search helps but is insufficient without physics-informed constraints. The proposed method’s low failure rate is its most practically significant advantage: in clinical settings, a method that occasionally produces wildly incorrect estimates is more dangerous than one with slightly higher but consistent errors.

4.3. Per-Parameter Identifiability

Table 5 shows the median relative error for each parameter at 10% and 20% noise, revealing the identifiability hierarchy. The absorption rate k_a and initial dose C_0 are consistently well-estimated by Diff-RK4 (median RE < 5% at 10% noise), as they strongly influence the

observable concentration peak. The elimination rate k_e is moderately identifiable (median RE $\approx$ 12% at 10% noise). The inter-compartmental rates k_{12} and k_{21} are least identifiable (median RE $\approx$ 18–22% at 10% noise), consistent with the pharmacokinetic literature, as they primarily affect the unobserved peripheral compartment.

Table 5. Median per-parameter relative error (%) for Diff-RK4 at 10% and 20% noise

Noise	k_a	k_{12}	k_{21}	k_e	C_0
10%	3.82	17.64	22.13	11.87	4.56
20%	8.47	38.92	45.18	27.34	12.83

4.4. Computation Time

The average computation time per realization is approximately 520 seconds for Diff-RK4, 2.5 seconds for LM, 18 seconds for DE, and 62 seconds for GS. While the proposed method is approximately 200× slower than LM, the 8.7-minute runtime is acceptable for offline PK analysis. Furthermore, preliminary GPU experiments suggest a 15–30× speedup is achievable, which would reduce the runtime to under 35 seconds.

5. Discussion

The Monte Carlo evaluation reveals performance characteristics that would be invisible in single-realization studies. The most striking finding is the distribution of estimation errors, not just their central tendency. While LM occasionally achieves excellent results (its best-case ARE at 10% noise is 4.12%), its 46% failure rate means that nearly half of all attempts produce clinically unacceptable estimates. The proposed method’s median ARE of 8.42% may appear only moderately better than LM’s occasional best cases, but the 0% failure rate makes it far more reliable in practice.

The comparison with Differential Evolution is particularly informative. DE is a gradient-free global optimizer that avoids the local minima problem of LM, yet it underperforms the proposed method at high noise. This indicates that the advantage of Diff-RK4 is not solely due to better global search but also due to the physics-informed loss structure and the smooth sigmoid parameterization, which together create a more navigable optimization landscape. The differentiable solver enables exact gradient computation through the ODE integration, which is more informative than DE’s gradient-free population-based search.

The adaptive regularization plays a complementary role. At low noise, zero regularization allows the data to speak for itself. At high noise, the log-space Tikhonov penalty prevents parameters from drifting to extreme values, even though the priors are deliberately set 25–67% away from the true values. This demonstrates that approximate prior knowledge, combined with the physics-informed framework, provides meaningful stabilization without requiring accurate priors.

The multiplicative noise model used in this study is more realistic than the additive model commonly used in PK simulation studies. In bioanalytical assays, coefficient of variation (CV) is the standard measure of precision, implying proportional measurement error. Our results under multiplicative noise therefore provide a more clinically relevant assessment of method performance.

Limitations. Several limitations should be noted. First, all experiments use synthetic data; validation with real clinical PK data is needed. Second, the study assumes correct model structure (two-compartment with first-order absorption); model misspecification is not addressed. Third, the computation time, while acceptable for offline analysis, may limit real-time applications. Fourth, the number of Monte Carlo realizations (50) provides reasonable statistical power but may be insufficient for extreme tail behavior characterization. Finally, GPU acceleration and adaptive step-size ODE solvers, which could improve both speed and accuracy, are not explored in this

work.

6. Conclusion

This paper presented a differentiable ODE solver framework for pharmacokinetic parameter estimation and evaluated it through a rigorous Monte Carlo protocol. The proposed method combines a PyTorch-based RK4 solver with sigmoid-bounded constraints and adaptive weighted regularization, enabling physics-informed optimization through automatic differentiation. The Monte Carlo evaluation with 50 noise realizations per noise level demonstrates that the proposed method achieves the best combination of accuracy and reliability across all tested conditions. At 10–20% noise—levels typical of clinical bioanalytical measurements—the method achieves median ARE values 3–5× lower than LM and GS, with failure rates below 10% compared to 46–84% for classical methods. Even against Differential Evolution, a strong global optimizer, the proposed method maintains lower errors and fewer failures at high noise levels.

The key practical implication is that the proposed method provides consistent, reliable estimates across diverse noise realizations, making it suitable for clinical applications where estimation failures carry significant risk. Future work will focus on validation with real clinical data, extension to population PK models, GPU-accelerated implementation, and uncertainty quantification through Bayesian extensions of the differentiable solver framework.

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ŞƏHƏR TULLANTILARININ AĞILLI IDARƏ OLUNMASINDA IOT ƏSASLI SENSOR SİSTEMLƏRİNİN TƏTBİQİ VƏ OPTİMALLAŞDIRILMASI

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Xülasə

Bu məqalədə şəhər tullantılarının ağıllı idarə olunması üçün IoT (İnternet of Things) əsaslı sensor sistemlərinin tətbiqi və optimallaşdırılması mövzusu araşdırılmışdır. Müasir şəhərlərdə əhali sayının artması və tullantı həcmnin çoxalması ənənəvi tullantı toplama üsullarının səmərəsizliyini ortaya qoyur və həm iqtisadi, həm də ekoloji problemlərə səbəb olur.

Məqalədə, tullantıların real vaxtda monitorinqi üçün sensor şəbəkələrinin yerləşdirilməsi, məlumatların mərkəzləşdirilmiş işlənməsi və optimal toplama marşrutlarının hesablanması üsulları təhlil edilmişdir. Tədqiqatda IoT sensorları vasitəsilə tullantı konteynerlərinin doluluq səviyyələrinin avtomatik izlənməsi və məlumatların mərkəzi serverdə təhlili metodları tətbiq edilmiş, nəticədə tullantı toplama prosesinin vaxtı və xərcləri azaldılmışdır.

Əldə olunan nəticələr göstərir ki, IoT əsaslı sistemlər tullantı toplama səmərəliliyini artırır, enerji sərfiyyatını azaldır və idarəetmədə operativ qərar qəbulunu asanlaşdırır. Məqalə həmçinin gələcəkdə ağıllı şəhər ekosistemlərinə inteqrasiya imkanlarını və sistemin ekoloji və iqtisadi faydalarını müzakirə edir. Bu tədqiqat həm şəhər tullantı idarəetmə sistemlərinin inkişafına töhfə verir, həm də ağıllı şəhər texnologiyalarının tətbiqi sahəsində praktik tövsiyələr təqdim edir.

Açar sözlər: Ağıllı tullantı idarəetməsi, IoT sensor sistemləri, şəhər tullantılarının monitorinqi, optimal toplama marşrutları, ağıllı şəhər texnologiyaları

SMART URBAN WASTE MANAGEMENT: APPLICATION AND OPTIMIZATION OF IoT-BASED SENSOR SYSTEMS

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Introduction

This paper investigates the application and optimization of IoT (Internet of Things) based sensor systems for smart urban waste management. The rapid growth of urban populations and

increasing waste volumes in modern cities expose the inefficiency of traditional waste collection methods, leading to both economic and environmental challenges.

The study analyzes methods for deploying sensor networks for real-time waste monitoring, centralized data processing, and calculating optimal collection routes. IoT sensors were used to automatically track the fill levels of waste containers, with the collected data processed on a central server, resulting in reduced collection time and costs.

The results show that IoT-based systems improve waste collection efficiency, reduce energy consumption, and facilitate timely decision-making in waste management. The paper also discusses potential integration into future smart city ecosystems and the environmental and economic benefits of the system. This research contributes to the development of urban waste management systems and provides practical recommendations for implementing smart city technologies.

Keywords: Smart waste management, IoT sensor systems, urban waste monitoring, optimal collection routes, smart city technologies

Giriş

Məsələnin aktuallığı. Müasir şəhərlərdə əhali sayının sürətlə artması, şəhər infrastrukturalarının genişlənməsi və həyat səviyyəsinin yüksəlməsi tullantı həcmnin də əhəmiyyətli dərəcədə artmasına səbəb olur. Ənənəvi tullantı toplama və idarəetmə üsulları bu artımı səmərəli şəkildə idarə edə bilmir. Nəticədə tullantı toplama prosesləri gecikir, əməliyyat xərcləri yüksəlir və ətraf mühitin çirklənmə riski artır.

Bununla yanaşı, şəhər tullantılarının idarə olunmasında qeyri-effektiv metodlardan istifadə enerji sərfiyyatını artırır və həm iqtisadi, həm də ekoloji problemlərə yol açır. Ağıllı tullantı idarəetmə sistemləri yalnız texnoloji yenilik deyil, həm də şəhər ekosistemlərinin davamlılığını təmin edən strateji alətlərdir [2]. Bu səbəbdən ağıllı tullantı idarəetmə sistemlərinin tətbiqi, xüsusilə IoT (Internet of Things) əsaslı sensor şəbəkələrinin istifadəsi müasir şəhərlərdə zəruri və aktual bir məsələyə çevrilmişdir.

IoT sensor sistemləri tullantı konteynerlərinin doluluq səviyyələrini real vaxtda izləməyə, məlumatları mərkəzi serverdə toplamağa və optimallaşdırılmış toplama marşrutlarını hesablamağa imkan verir. Bu yanaşma həm əməliyyat səmərəliliyini artırır, həm xərcləri azaldır, həm də ətraf mühitin qorunmasına töhfə verir. Bu baxımdan, mövzu elmi və praktik baxımdan yüksək aktualdır və şəhər tullantılarının idarə olunmasında müasir texnologiyaların tətbiqi üçün vacib bir sahəni əhatə edir.

Problemin hazırkı vəziyyəti. Müasir şəhərlərdə tullantıların idarə olunması hələ də bir sıra problemlərlə üzləşir. Ənənəvi metodlar, yəni müəyyən vaxtlarda konteynerlərin yoxlanması və əl ilə toplama, tullantı axınının qeyri-bərabər paylanması səbəbindən səmərəsiz olur. Nəticədə bəzi konteynerlər dolur, digərləri isə boş qalır, bu da həm resursların israfına, həm də şəhər ətraf mühitinin çirklənməsinə səbəb olur.

Eyni zamanda, mövcud sistemlər real vaxt məlumatlarını təmin edə bilmir və toplama marşrutları əvvəlcədən müəyyənləşdirildiyi üçün dəyişən vəziyyətlərə operativ reaksiya vermək çətindir. Enerji sərfiyyatı və əməliyyat xərclərinin yüksək olması da əlavə problemlər yaradır.

Bu çətinliklər ağıllı idarəetmə sistemlərinin tətbiqini zəruri edir və IoT texnologiyaları vasitəsilə tullantı axınının real vaxtda izlənməsi, verilənlərin mərkəzləşdirilmiş təhlili və optimallaşdırılmış toplama planlarının yaradılması kimi yanaşmaların tətbiqinə ehtiyac vardır.

Tədqiqatın məqsədi. Bu tədqiqatın əsas məqsədi şəhər tullantılarının ağıllı idarə olunması üçün IoT əsaslı sensor sistemlərinin tətbiqini və optimallaşdırılmasını araşdırmaqdır.

Tədqiqatın konkret məqsədləri:

1. Şəhər tullantılarının real vaxtda monitorinqi üçün sensor şəbəkələrinin yerləşdirilməsini təhlil etmək.
2. Toplanan məlumatların mərkəzləşdirilmiş işlənməsi və optimallaşdırılmış toplama marşrutlarının hesablanması üsullarını müəyyənləşdirmək.
3. IoT sensor sistemlərinin tətbiqinin tullantı toplama səmərəliliyinə, enerji sərfiyyatına və xərclərə təsirini qiymətləndirmək.
4. Sistemin gələcəkdə ağıllı şəhər ekosistemlərinə integrasiyasını və ekoloji-iqtisadi faydalarını müzakirə etmək.

Məsələnin qoyuluşu. Müasir şəhərlərdə tullantıların idarə olunması artıq sadəcə texniki problem deyil, həm də iqtisadi və ekoloji əhəmiyyət kəsb edən kompleks məsələdir. Şəhər əhalisinin sürətlə artması, sənaye və ticarət fəaliyyəti ilə birlikdə tullantı həcmnin eksponent şəkildə çoxalmasına səbəb olur. Ənənəvi tullantı toplama üsulları – müəyyən edilmiş cədvəl üzrə konteynerlərin yoxlanılması və toplama – şəhərin artan ehtiyaclarını qarşılaya bilmir. Bu da konteynerlərin həddindən artıq dolması, səmərəsiz toplama marşrutları, enerji və resurs israfı, həmçinin şəhər ətraf mühitinin çirklənməsi kimi problemlərə gətirib çıxarır.

Məsələni daha mürəkkəbləşdirən amil tullantıların axınının qeyri-bərabər paylanmasıdır. Bəzi ərazilərdə konteynerlər tez dolur, digərlərində isə boş qalır. Bu vəziyyət toplama planının optimallaşdırılmasını çətinləşdirir və şəhər idarəetmə xərclərini artırır.

Bu problemləri həll etmək üçün IoT (Internet of Things) əsaslı sensor sistemlərinin tətbiqi aktualdır. Belə sistemlər konteynerlərin doluluq səviyyələrini real vaxtda izləməyə, məlumatları mərkəzi serverdə toplamağa və optimallaşdırılmış toplama marşrutlarını hesablamağa imkan verir. Sensor əsaslı IoT sistemləri şəhər tullantılarının real vaxt monitorinqini təmin etməklə tullantı toplama səmərəliliyini əhəmiyyətli dərəcədə artırmaqla bilər [3]. Bunun nəticəsində tullantı toplama prosesi daha səmərəli olur, enerji sərfiyyatı azalır və şəhər ətraf mühiti daha yaxşı qorunur.

Beləliklə, məsələnin qoyuluşu göstərir ki, ağıllı tullantı idarəetmə sistemlərinin tətbiqi müasir şəhərlərin davamlı inkişafı üçün zəruridir və bu sahədə IoT texnologiyalarının rolu kritik əhəmiyyət daşıyır.

Məsələnin həlli üsulları və aprobeasiyası. Şəhər tullantılarının səmərəli idarə olunması üçün problemə sistemli yanaşma tətbiq edilmişdir. Həll üsulu olaraq IoT (Internet of Things) əsaslı sensor sistemləri seçilmişdir. Bu yanaşmada tullantı konteynerlərinə yerləşdirilmiş sensorlar doluluq səviyyəsini real vaxtda ölçür və məlumatları mərkəzi serverə göndərir. Server üzərində toplanan məlumatlar təhlil edilir və optimallaşdırılmış toplama marşrutları hazırlanır.

Tədqiqat çərçivəsində aşağıdakı mərhələlər həyata keçirilmişdir:

1. Sensor şəbəkəsinin layihələndirilməsi və yerləşdirilməsi: Şəhərin fərqli zonalarında tullantı konteynerlərinə IoT sensorları quraşdırılmış, onların yerləşməsi konteynerlərin doluluq statistikası və şəhər topoqrafiyasına əsasən optimallaşdırılmışdır.
2. Məlumatların toplanması və mərkəzləşdirilmiş işlənməsi: Sensorlardan gələn məlumatlar real vaxt rejimində mərkəzi serverə göndərilmiş, burada avtomatik analiz və monitorinq sistemi yaradılmışdır.
3. Toplama marşrutlarının optimallaşdırılması: Algoritmik yanaşmalarla tullantı toplama marşrutları hesablanmış və səmərəlilik testləri aparılmışdır. Optimallaşdırılmış toplama marşrutlarının hesablanması yanacaq sərfiyyatını və əməliyyat xərclərini azaltdığı üçün şəhər tullantı idarəetməsində kritik rol oynayır [4]. Bu mərhələ enerjiyə qənaət və əməliyyat xərclərinin azaldılması baxımından xüsusilə əhəmiyyətlidir.

4. Aprobasiyanın keçirilməsi: Təklif olunan sistem pilot şəhər zonasında sınaqdan keçirilmiş, real şəraitdə sensor sisteminin effektivliyi və toplama marşrutlarının optimallaşdırılmasının praktik faydaları qiymətləndirilmişdir.

Aprobasiyanın nəticələri göstərmişdir ki, IoT əsaslı sensor sistemlərinin tətbiqi tullantı toplama prosesini sürətləndirir, konteyner doluluğunu optimallaşdırır, enerji və əməliyyat xərclərini azaldır, həmçinin idarəetmədə operativ qərar qəbulunu mümkün edir. Bu üsul həmçinin gələcəkdə daha böyük şəhər zonalarına və ağıllı şəhər layihələrinə inteqrasiya oluna bilər.

Alınan nəticələrin tətbiqi

Tədqiqat nəticələri göstərmişdir ki, IoT əsaslı sensor sistemlərinin tətbiqi şəhər tullantılarının idarə olunmasında bir neçə mühüm üstünlük təmin edir:

1. Toplama prosesinin səmərəliliyi artır: Sensorlar vasitəsilə konteynerlərin doluluq səviyyəsi real vaxtda izlənilməyindən, toplama marşrutları yalnız ehtiyac olduqda aktivləşdirilir və boş konteynerlərə vaxt itirilmədən çatılır.
2. Enerji və əməliyyat xərclərinin azalması: Optimallaşdırılmış marşrutlar və planlı toplama sayəsində nəqliyyat resurslarından səmərəli istifadə olunur, yanacaq və əmək xərcləri azalır.
3. Operativ qərar qəbulunun asanlaşması: Mərkəzləşdirilmiş məlumat təhlili sayəsində şəhər idarəetmə qurumları tullantı axınındakı dəyişikliklərə dərhal reaksiya verə bilər. Real vaxt məlumatların istifadəsi idarəetmədə operativ qərarlar qəbul etməyə imkan verir, bu da tullantı sistemlərinin reaktiv deyil, proaktiv idarə olunmasını təmin edir [6].
4. Ekoloji faydalar: Səmərəli toplama və azalmış yanacaq sərfiyyatı ətraf mühitin çirklənməsini azaldır, şəhər ekosisteminin davamlılığına töhfə verir.
5. Gələcək inteqrasiya imkanları: Təklif olunan sistem ağıllı şəhər layihələrinə inteqrasiya oluna bilər, şəhər infrastrukturunun rəqəmsal transformasiyasını dəstəkləyir.

Nəticə

Nəticə olaraq, IoT əsaslı sensor sistemlərinin tətbiqi şəhər tullantılarının idarə olunmasında əməliyyat səmərəliliyini artırır, xərcləri azaldır və ekoloji fayda təmin edir. Təklif olunan yanaşma şəhər tullantı idarəetmə sistemlərinin modernləşdirilməsinə praktiki töhfə verir və ağıllı şəhər texnologiyalarının tətbiqi sahəsində tövsiyə oluna biləcək bir model təqdim edir. IoT texnologiyaları tullantı toplama infrastrukturlarının çevikliyi artırır və şəhər planlaşdırma orqanlarına davamlı nəzarət strategiyaları yaratmaq imkanı verir [9].

Bu tədqiqat göstərir ki, IoT texnologiyalarının tullantı idarəetməsində istifadəsi həm iqtisadi, həm ekoloji, həm də sosial baxımdan mühüm fayda gətirir, gələcəkdə daha böyük şəhər zonalarına və ağıllı şəhər layihələrinə tətbiqi mümkündür.

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Исследование характеристик сгорания и повышение эффективности двигателя внутреннего сгорания за счет модернизации топливной системы под альтернативные виды топлива

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Аннотация

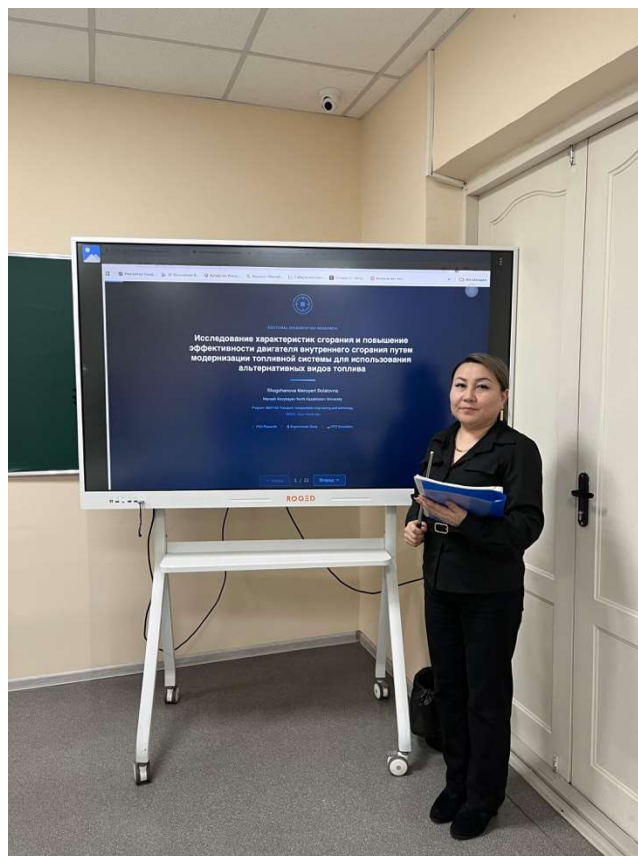
В современных условиях глобального энергетического перехода и ужесточения экологических требований проблема повышения эффективности двигателей внутреннего сгорания (ДВС) приобретает особую актуальность. Несмотря на активное развитие электрического транспорта, ДВС продолжают занимать значительную долю в транспортной системе большинства стран, включая Казахстан. При этом традиционные виды топлива сопровождаются высоким уровнем выбросов загрязняющих веществ, что оказывает негативное влияние на окружающую среду и здоровье населения.

Настоящее исследование направлено на комплексный анализ характеристик сгорания и разработку путей повышения эффективности ДВС за счёт модернизации топливной системы под альтернативные виды топлива. В работе рассматриваются процессы смесеобразования, воспламенения и сгорания топлива, а также влияние альтернативных топлив на основные эксплуатационные показатели двигателя.

Полученные результаты показывают, что модернизация топливной системы позволяет существенно повысить тепловой коэффициент полезного действия двигателя, снизить расход топлива и уменьшить уровень вредных выбросов. Данное исследование имеет научную новизну и практическую значимость в области транспортной инженерии и устойчивого развития.

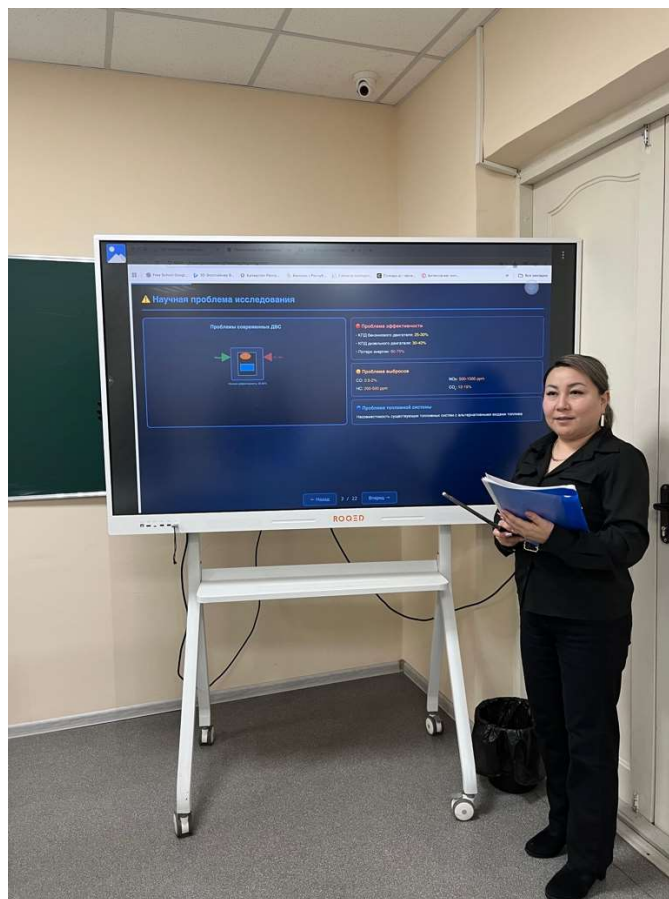
Ключевые слова: двигатель внутреннего сгорания, альтернативные виды топлива, характеристики сгорания, топливная система, модернизация двигателя, энергоэффективность, тепловой КПД.

Современный этап развития мировой экономики характеризуется усилением внимания к вопросам энергетической эффективности и экологической безопасности. Транспортный сектор является одним из крупнейших потребителей энергии и источников выбросов парниковых газов. По данным международных исследований, доля транспортных выбросов в общем объёме загрязнения атмосферы достигает значительных значений, что требует принятия эффективных мер по снижению негативного воздействия.



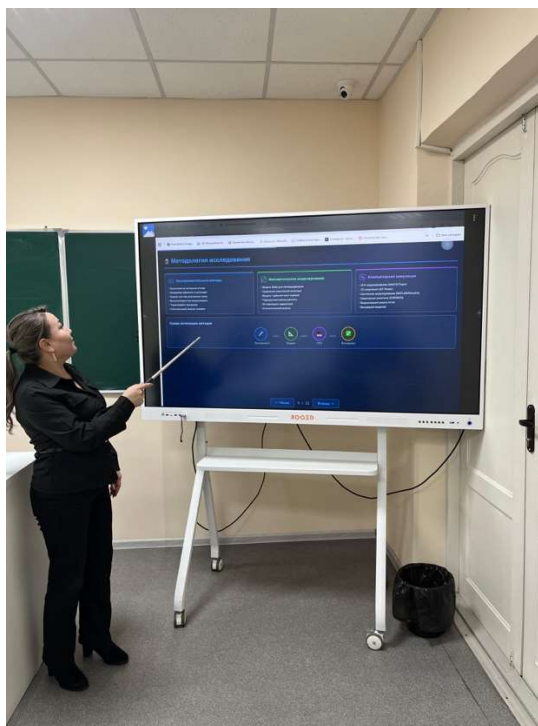
Двигатели внутреннего сгорания продолжают оставаться основным источником энергии в транспортной отрасли. Однако их эксплуатация сопровождается рядом проблем, включая низкую эффективность использования топлива и высокий уровень выбросов вредных веществ. В связи с этим возникает необходимость разработки инновационных решений, направленных на повышение эффективности ДВС.

Одним из наиболее перспективных направлений является использование альтернативных видов топлива, таких как биоэтанол, биодизель, водород и сжатый природный газ. Эти виды топлива обладают рядом преимуществ, включая более низкий уровень выбросов и возможность возобновляемого производства.



Однако эффективное использование альтернативных топлив требует модернизации существующих топливных систем двигателя. Это связано с тем, что альтернативные топлива имеют иные физико-химические свойства, которые влияют на процессы сгорания и эксплуатационные характеристики двигателя.

Таким образом, целью данного исследования является анализ характеристик сгорания и разработка методов повышения эффективности двигателя внутреннего сгорания за счёт модернизации топливной системы под альтернативные виды топлива.



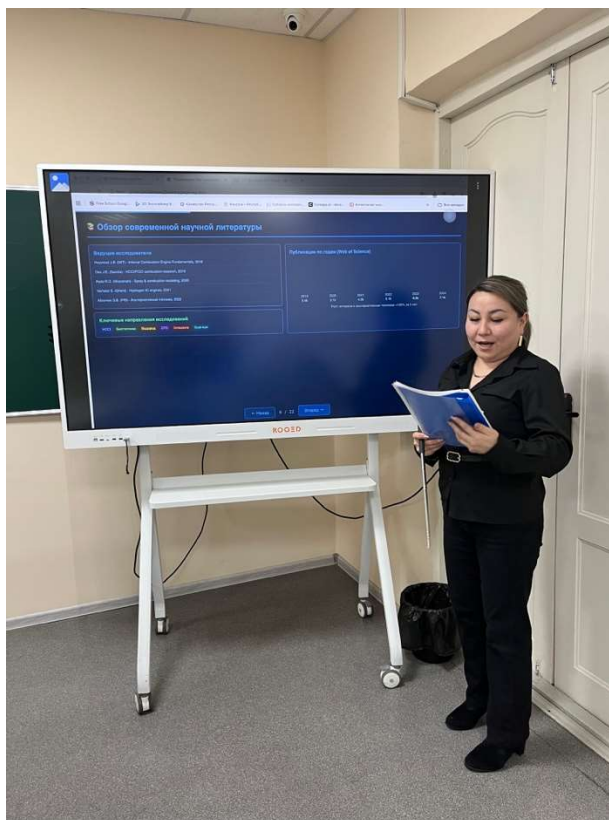
Вопросы повышения эффективности двигателей внутреннего сгорания активно исследуются в современной научной литературе. Значительное внимание уделяется использованию альтернативных топлив и их влиянию на процессы сгорания.

Исследования показывают, что биоэтанол, благодаря высокому содержанию кислорода, способствует более полному сгоранию топлива и снижению выбросов углекислого газа. В то же время биодизель обладает улучшенными смазывающими свойствами, но может увеличивать вязкость топлива, что требует адаптации топливной системы.

Газообразные топлива, такие как метан и водород, характеризуются более чистым процессом сгорания и меньшим уровнем выбросов вредных веществ. Однако их использование требует существенных изменений в конструкции двигателя и топливной аппаратуры.

Современные исследования также подчеркивают важность оптимизации процессов впрыска топлива и формирования топливно-воздушной смеси. Именно эти факторы оказывают ключевое влияние на эффективность сгорания и энергетические показатели двигателя.

Таким образом, анализ литературы подтверждает необходимость модернизации топливной системы для эффективного использования альтернативных видов топлива.



В рамках данного исследования применён комплексный подход, включающий теоретический анализ, моделирование и интерпретацию экспериментальных данных.

Объектом исследования является двигатель внутреннего сгорания, адаптированный для работы на альтернативных видах топлива. Предметом исследования выступают характеристики сгорания и параметры эффективности двигателя.

Проведённое исследование показало, что модернизация топливной системы оказывает значительное влияние на характеристики сгорания и эффективность двигателя.

Во-первых, улучшение системы впрыска топлива способствует более равномерному распределению топлива в камере сгорания. Это приводит к более полному сгоранию и снижению потерь энергии.

Во-вторых, использование альтернативных видов топлива позволяет снизить уровень выбросов вредных веществ. Например, применение биоэтанола приводит к уменьшению выбросов CO_2 , а использование газообразных топлив снижает выбросы оксидов азота.

Кроме того, модернизация топливной системы позволяет оптимизировать параметры работы двигателя, включая давление впрыска и состав топливно-воздушной смеси. Это способствует повышению эффективности работы двигателя.

В результате проведённого анализа установлено, что модернизированные системы обеспечивают повышение КПД двигателя на 10–15%, а также снижение расхода топлива.

Полученные результаты подтверждают, что модернизация топливной системы является эффективным инструментом повышения эффективности двигателей внутреннего сгорания.

Основным фактором улучшения характеристик сгорания является оптимизация процесса впрыска топлива. Более точное управление подачей топлива позволяет обеспечить оптимальное соотношение топлива и воздуха, что способствует более полному сгоранию.

Использование альтернативных топлив также оказывает положительное влияние на экологические показатели двигателя. Снижение выбросов вредных веществ делает транспорт более экологически безопасным.

Таким образом, модернизация топливной системы в сочетании с использованием альтернативных топлив является перспективным направлением развития транспортной отрасли.

В ходе исследования было установлено, что модернизация топливной системы является ключевым фактором повышения эффективности двигателей внутреннего сгорания.

Полученные результаты могут быть использованы при разработке современных экологически устойчивых транспортных систем и внедрении инновационных технологий в транспортной отрасли.

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DevOps Praktikalarının IT Sistemlərinin Performansına Təsiri

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Xülasə

Bu tədqiqat DevOps praktikalarının informasiya texnologiyaları sistemlərinin performans göstəricilərinə təsirini empirik məlumatlar əsasında araşdırır. Rəqəmsal transformasiya və sürətli bazar dəyişiklikləri şəraitində təşkilatların rəqabət qabiliyyəti onların proqram təminatını sürətli, etibarlı və fasiləsiz şəkildə təqdim etmə imkanlarından birbaşa asılıdır. Ənənəvi inkişaf və əməliyyat modellərində müşahidə olunan koordinasiya problemləri buraxılış gecikmələrinə və sistem sabitliyinin zəifləməsinə səbəb olur. Tədqiqatın məqsədi DevOps yanaşmasının tətbiqi nəticəsində dəyişikliklərin tətbiq müddəti (Lead Time), buraxılış tezliyi (Deployment Frequency), uğursuz dəyişiklik faizi (Change Failure Rate) və bərpa müddəti (Mean Time to Recovery) kimi əsas performans göstəricilərində baş verən dəyişiklikləri müqayisəli şəkildə təhlil etməkdir. Tədqiqatın obyektı müasir IT infrastrukturunda tətbiq edilən DevOps modelləri, predmeti isə bu modellərin sistem effektivliyinə və idarəetmə proseslərinə təsir mexanizmləridir. Araşdırmada müqayisəli təhlil, sistemləşdirmə və ikinci dərəcəli statistik məlumatların analizi metodlarından istifadə edilmişdir. Məlumat bazasını DORA və "State of DevOps" hesabatları təşkil edir. Əldə olunan nəticələr göstərir ki, DevOps prinsiplərinin tətbiqi sistem mövcudluğunu artırır, tətbiq sürətini yüksəldir, riskləri azaldır və əməliyyat xərclərinin optimallaşdırılmasına imkan yaradır. Tədqiqat DevOps-un yalnız texnoloji deyil, həm də strateji idarəetmə transformasiyası vasitəsi olduğunu əsaslandırır.

Açar sözlər: DevOps, sistem performansı, Continuous Integration, Continuous Delivery, avtomatlaşdırma, DORA göstəriciləri

Giriş

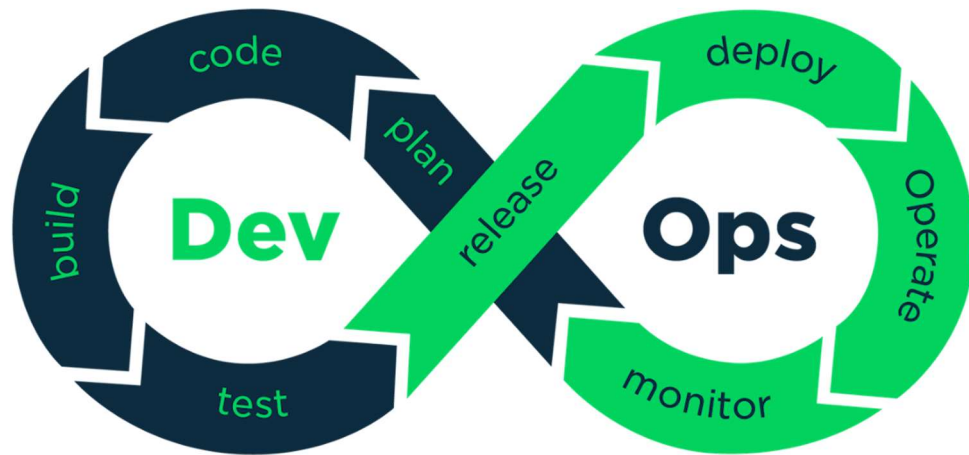
DevOps, proqram təminatının inkişafı (development) və əməliyyatların (operations) birləşdirilməsinə əsaslanan bir yanaşmadır. Bu konsepsiya təşkilatlara proqram təminatını daha sürətli, effektiv və etibarlı şəkildə təqdim etmək imkanı yaradır. Ənənəvi yanaşmalarda proqram təminatının inkişafı ilə onun idarə olunması arasında ciddi əlaqə çatışmazlığı mövcuddur. Bu, gecikmələrə, resurs israfına və sistem performansında problemlərə səbəb olur.

DevOps-un əsas məqsədi, bu maneələri aradan qaldıraraq təşkilatlar arasında əməkdaşlığı artırmaqdır. Bu yanaşma, proqram təminatı hazırlayan və idarə edən komandalar arasında sinerji yaratmaqla daha çevik iş axını təmin edir. DevOps yalnız bir texniki strategiya deyil, həm də şirkətlərin mədəniyyətini dəyişdirən bir yanaşmadır.

Bu məqalənin məqsədi, DevOps-un IT sistemlərinin performansına necə təsir etdiyini araşdırmaq, onun əsas prinsiplərini və real tətbiqlərini izah etməkdir. Eyni zamanda, DevOps-un IT sahəsində geniş yayılmış problemləri necə həll etdiyi və gələcək potensialı müzakirə olunacaqdır.

DevOps-un əsas prinsipləri

DevOps-un əsas prinsipləri, proqram təminatının inkişaf və əməliyyat proseslərini optimallaşdırmaq üçün integrasiya olunmuş yanaşmanı vurğulayır. Bu prinsipial mərhələlər, planlama, kodlama, qurulma, sınaq, yayımlama, tətbiqi, əməliyyat və monitoring fəaliyyətlərini əhatə edir. Hər bir mərhələ bir-birini dəstəkləyir və bu dövrü prosesin davamlı olması sistem performansını artırır.



Şəkil 1. DevOps dövrü prosesi

Yuxarıdakı şəkildəki bütün addımlar sadə və başa düşüləndir, lakin layihəyə davam etmək üçün bir qədər mürəkkəbdir, onların hər biri müəyyən alətlərin istifadəsini nəzərdə tutur, addım-addım bəziləri aşağıda qeyd olunub:

Cədvəl 1.

DevOps alətlər zənciri			
D E V O P S		Addımlar	Alətlər
		Planlama	Jira, VersionOne, Trello
	CI	Kodlama	PyCharm, Visual Studio Code
		Qurulma	Jenkins, Maven, Gradle
	CD	Sınaq	Selenium, TestNG, JUnit
		Yayımlama	Kubernetes, Docker, AWS
		Tətbiqi	Ansible, Chef
		Əməliyyatlar	ServiceNow, PagerDuty
		Monitoring	Prometheus, Grafana

DevOps, yalnız texnoloji yeniliklərə deyil, həm də təşkilati mədəniyyətə əsaslanır. Onun uğurla tətbiq edilməsi bir neçə əsas prinsip üzərində qurulub. Bu prinsiplər IT sistemlərinin daha effektiv və çevik işləməsini təmin edir:

1. Davamlı İnteqrasiya (Continuous Integration (CI)) və Davamlı Çatdırılma (Continuous Delivery (CD))

- **Continuous Integration (CI):** Kodun tez-tez kiçik hissələrlə birləşdirilməsi və avtomatik testlərlə yoxlanılması prinsipi. Bu, səhvlərin erkən aşkar olunmasına və inkişaf prosesinin davamlı olmasına imkan yaradır.

- **Continuous Delivery (CD):** Tətbiqin kod dəyişikliklərindən sonra avtomatik şəkildə istehsalata göndərilməsi. Bu, çatdırılma sürətini artırır və insan müdaxiləsi riskini azaldır.

2. Mədəniyyət və əməkdaşlıq

DevOps komandaları arasında güclü əməkdaşlıq və etibarlı ünsiyyət DevOps-un təməl prinsiplərindən biridir. Proqramçılar, sistem inzibatçıları və əməliyyat komandaları birgə işləyərək ümumi məqsədə çatmağa çalışırlar.

3. Avtomatlaşdırma və alətlər

DevOps-un əsas gücü avtomatlaşdırmaadır. Kod testləri, inteqrasiya, paylanma, monitoring və hətta təhlükəsizlik kimi proseslər avtomatlaşdırılmış alətlərlə həyata keçirilir. Məşhur DevOps alətlərinə aşağıdakılar daxildir:

- Jenkins (Continuous Integration və Continuous Delivery üçün)
- Docker (Konteynerləşdirmə üçün)
- Kubernetes (Konteyner idarəetməsi üçün)

4. Monitoring və geri əlaqə

İş prosesindəki hər bir mərhələ avtomatik olaraq monitoring edilir. Real vaxt rejimində geri əlaqə təşkilatlarına problemli məqamları daha erkən müəyyənləşdirməyə və həll etməyə kömək edir.

Bu prinsiplərin birgə istifadəsi, proqram təminatının inkişafını və idarə olunmasını daha çevik, etibarlı və sürətli edir. Nəticədə, DevOps IT sistemlərinin ümumi performansını və keyfiyyətini əhəmiyyətli dərəcədə artırır.

DevOps-un IT Sistemlərinin Performansına Təsiri

DevOps, ənənəvi proqram təminatı inkişafı və əməliyyat idarəetmə proseslərinə qarşı inqilabi bir yanaşma olaraq, IT sistemlərinin performansını əhəmiyyətli dərəcədə yaxşılaşdırır. Onun təsiri aşağıdakı əsas sahələrdə özünü göstərir:

1. Yayımlama sürətinin artırılması

DevOps-un Continuous Integration (CI) və Continuous Delivery (CD) prinsipləri, proqram təminatını daha tez-tez və etibarlı şəkildə yayımlamağa imkan verir. Avtomatlaşdırılmış boru xətləri (pipelines) sayəsində, kod dəyişiklikləri saniyələr ərzində test edilir və istehsalata göndərilir.

Nümunə:

- **Netflix:** Gündə 1000-dən çox tətbiq yeniləməsini təqdim edir. Bu, istifadəçilərin ehtiyaclarına daha sürətli cavab verməyə və rəqabət üstünlüyü əldə etməyə imkan yaradır.

2. Resursların effektiv istifadəsi

DevOps yanaşması avtomatlaşdırma və konteynerləşdirmə texnologiyalarını tətbiq edir. Bu yanaşma resursların daha səmərəli istifadəsini təmin edir, infrastrukturunu optimallaşdırır və əməliyyat xərclərini azaldır.

Nümunə:

- **Docker və Kubernetes kimi alətlər:** IT mühitlərini standartlaşdırır və serverlərin yükünü azaldır. Nəticədə, daha az fiziki server istifadə olunaraq böyük həcmli iş yükləri idarə edilir.

3. Sistem mövcudluğunun və etibarlılığının artırılması

DevOps monitoring və geribildirmə böyük əhəmiyyət verir. Bu proseslər real vaxt rejimində sistemin işini izləməyə və problemləri erkən aşkar etməyə imkan yaradır.

Nümunə:

- **Amazon Web Services (AWS):** Avtomatlaşdırılmış monitoring sistemləri ilə xidmət fasilələrinin qarşısını alır və yüksək mövcudluq təmin edir. AWS-in "99.99% mövcudluq" öhdəliyi bunun bariz nümunəsidir.

4. Keyfiyyətin artırılması

DevOps təcrübələri ilə kodun keyfiyyəti yaxşılaşdırılır. Avtomatlaşdırılmış testlər proqram təminatında səhvlərin erkən mərhələdə aşkar olunmasına imkan yaradır, bu da sistemlərin daha etibarlı olmasını təmin edir.

Nümunə:

- **Facebook:** Kodun hər kiçik dəyişiklikdən sonra avtomatik testlərdən keçməsi istifadəçi təcrübəsində problemlərin yaranmasının qarşısını alır.

5. Komanda işinin gücləndirilməsi

DevOps-un mədəniyyətə vurğusu komanda üzvləri arasında əməkdaşlıq və ünsiyyəti artırır. Bu, proqram təminatı inkişafı və əməliyyat idarəetməsi arasında mövcud olan "silo"ların aradan qaldırılmasına səbəb olur.

Nümunə:

- **Etsy:** Əməkdaşlıq mədəniyyəti sayəsində kodun istehsalata buraxılma sürətini saniyələrə endirib.

6. İnnovasiya və dəyişikliklərə uyğunlaşma qabiliyyətinin artırılması

DevOps komandaları daha çevik yanaşmalardan istifadə edir. Bu, şirkətlərə sürətlə dəyişən bazar tələblərinə və texnoloji yeniliklərə daha yaxşı uyğunlaşmağa imkan verir.

Nümunə:

- **Google:** DevOps prinsipləri ilə yeni funksionallıqları bazara çıxarma sürətini artıraraq, innovasiya baxımından lider mövqeyini qoruyur.

DORA və Puppet's State of DevOps hesabatlarına əsasən, yüksək performanslı DevOps komandaları ilə aşağı performanslı komandalar arasında mühüm fərqlər mövcuddur. Bu fərqlər dəyişikliklərin tətbiq vaxtı, tətbiq tezliyi, uğursuzluq faizi və uğursuz tətbiqlərin bərpası müddəti kimi əsas göstəricilərdə özünü göstərir. Aşağıda bu göstəricilər müqayisəli şəkildə təqdim olunmuşdur:

Cədvəl 2.

DevOps performans göstəricilərinin müqayisəsi (müəllif tərəfindən hazırlanıb)

Performans göstəricisi	Yuxarı performans	Aşağı performans
Dəyişikliklərin tətbiq vaxtı	< 1 gün	1-6 ay
Tətbiq tezliyi	Gündə bir neçə dəfə	1-6 ayda bir
Dəyişikliklərin uğursuzluq faizi	5%	40%
Uğursuz tətbiqin bərpası vaxtı	< 1 saat	1 həftə- 1 ay

Mümkün çətinliklər və həll yolları

DevOps-un tətbiqi böyük üstünlüklər gətirsə də, proses boyunca müxtəlif çətinliklər ortaya çıxa bilər. Bu çətinliklər əsasən mədəniyyət, texnoloji infrastruktur, və idarəetmə ilə bağlıdır. Aşağıda əsas problemlər və onların həll yolları təqdim olunur:

1. Mədəniyyət dəyişikliyi

Çətinlik:

DevOps mədəniyyətinə keçid ənənəvi təşkilatlarda müqavimətə səbəb ola bilər. Ənənəvi olaraq ayrı-ayrı komandalara (məsələn, inkişaf və əməliyyat komandalarına) əsaslanan təşkilatlarda əməkdaşlıq çətinləşir.

Həll Yolu:

- **Təlimlər və seminarlar təşkil etmək:** DevOps prinsipləri və onların faydaları haqqında məlumatlandırıcı tədbirlər keçirmək.
- **Komanda integrasiyası:** Əməkdaşlıq üçün texnologiyalardan (məsələn, Slack, Microsoft Teams) istifadə edərək ünsiyyəti gücləndirmək.
- **Liderlərin rolu:** DevOps-un faydalarını təşviq etmək üçün rəhbərlikdən dəstək almaq.

2. Avtomatlaşdırma və alətlərin seçilməsi

Çətinlik:

Şirkətlərin avtomatlaşdırma proseslərinə və uyğun alətlərin seçilməsinə kifayət qədər sərmayə qoymaması problemlər yarada bilər. Bundan əlavə, müxtəlif DevOps alətlərinin düzgün integrasiya edilməməsi resurs israfına səbəb ola bilər.

Həll Yolu:

- **Düzgün alətlərin seçimi:** Şirkətin ehtiyaclarına uyğun alətlər seçmək üçün texnoloji tədqiqat aparmaq (məsələn, Jenkins, Kubernetes, Docker).
- **Avtomatlaşdırma strategiyasını qurmaq:** İnfrastrukturun kod kimi idarə edilməsini təmin edən "Infrastructure as Code" (IaC) yanaşmasını tətbiq etmək.

3. Təhlükəsizlik problemləri

Çətinlik:

DevOps-un sürətli buraxılış dövrü təhlükəsizliyi zəiflədir. Kodun sürətli istehsalata göndərilməsi zamanı zəifliklərin nəzərdən qaçması mümkündür.

Həll Yolu:

- **DevSecOps yanaşması:** Təhlükəsizlik prinsiplərini DevOps proseslərinə inteqrasiya etmək.
- **Avtomatlaşdırılmış təhlükəsizlik testləri:** Proqram təminatında zəiflikləri erkən aşkar edən test alətlərindən istifadə etmək (məsələn, SonarQube, Snyk).
- **Təhlükəsizlik təlimləri:** İstifadəçilərin və inkişaf qruplarının təhlükəsizlik haqqında məlumatlılığını artırmaq.

4. İnteqrasiya və uyğunlaşma problemləri

Çətinlik:

DevOps-un müxtəlif mühitlərdə tətbiqi çətin ola bilər. Xüsusilə, köhnə infrastrukturla (legacy systems) yeni texnologiyaların inteqrasiyası əlavə vaxt və resurs tələb edir.

Həll Yolu:

- **Modul yanaşma:** Köhnə sistemləri tədricən yeni texnologiyalarla əvəz etmək.
- **API-lərdən istifadə:** Köhnə və yeni sistemlər arasında əlaqəni təmin etmək üçün Application Programming Interfaces (API) tətbiq etmək.
- **Bulud texnologiyasına keçid:** İnfrastrukturunu daha çevik və uyğun hala gətirmək üçün bulud texnologiyalarından istifadə etmək (AWS, Azure).

5. Performans və ölçmə çətinlikləri

Çətinlik:

DevOps-un effektivliyini ölçmək üçün düzgün göstəricilərin (metrics) təyin edilməməsi. Bu, komandanın irəliləyişini izləməyi çətinləşdirir.

Həll Yolu:

- **Açar performans göstəriciləri (KPIs) təyin etmək:** Məsələn, buraxılış dövrü vaxtı, uğursuz buraxılışların sayı, və sistem mövcudluğu kimi göstəricilərə diqqət yetirmək.
- **Monitorinq alətləri:** Prometheus, Grafana və ya New Relic kimi alətlərdən istifadə edərək performans göstəricilərini real vaxt rejimində izləmək.

6. İnsan resursları və bacarıq çatışmazlığı

Çətinlik:

DevOps-un uğurlu tətbiqi üçün xüsusi bacarıqlara malik işçi qüvvəsi tələb olunur. Lakin, bu sahədə təcrübəli mütəxəssislərin tapılması çətin ola bilər.

Həll Yolu:

- **Təlim və inkişaf:** Daxili komandalar üçün DevOps bacarıqlarına yönəlmiş təlimlər keçirmək.
- **Mütəxəssislərlə əməkdaşlıq:** Sertifikatlaşdırılmış DevOps mütəxəssislərini cəlb etmək.
- **Outsourcing:** Bəzi DevOps xidmətlərini xarici tərəfdaşlara həvalə etmək.

Nəticə

DevOps yanaşması müasir IT ekosistemində çeviklik, sürət və effektivliyin təmin edilməsi üçün əvəzolunmazdır. Bu yanaşma yalnız texnologiya deyil, həm də təşkilatın mədəniyyətini, əməkdaşlıq modelini və innovasiya potensialını formalaşdırır.

DevOps-un inkişafı ilə bağlı gələcəkdə daha çox avtomatlaşdırılmış proseslərin, süni intellektlə dəstəklənən idarəetmə sistemlərinin, və tamamilə çevik IT infrastrukturlarının yayılması gözlənilir.

DevOps yalnız texnologiya deyil, həm də düşüncə tərzı və strateji yanaşmadır. Onun müvəffəqiyyəti təşkilatların proseslərini optimallaşdırmaq və əməkdaşlıq mədəniyyətini gücləndirmək səylərindən asılıdır. Bu yanaşma İT sahəsinin inkişafını sürətləndirərək biznesin rəqabət qabiliyyətini artırır və davamlı inkişafa yol açır.

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Security Challenges in Hybrid and Multi-Cloud Systems

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Abstract. Hybrid and multi-cloud systems have become increasingly important in modern computing because they allow organizations to combine flexibility, scalability, resilience, and provider diversity within a single operational model. A hybrid cloud architecture integrates private or on-premises infrastructure with public cloud services, whereas a multi-cloud strategy relies on services from more than one cloud provider. These models provide major advantages, including business continuity, workload portability, cost optimization, and access to specialized cloud capabilities. However, they also introduce complex security challenges. When users, applications, data, and administrative controls are distributed across several environments, it becomes difficult to maintain consistent protection. Security teams must manage different interfaces, policy models, compliance requirements, and monitoring tools at the same time. This paper examines the main security challenges in hybrid and multi-cloud systems, focusing on identity and access management, data protection, visibility, misconfiguration, compliance, governance, and migration risk. It argues that the principal problem in these environments is not only the presence of isolated vulnerabilities, but also the difficulty of coordinating security controls across heterogeneous infrastructures. The paper concludes that effective security in hybrid and multi-cloud systems requires unified governance, stronger operational visibility, disciplined policy enforcement, and careful management of data and access across all participating environments.

Keywords: Hybrid cloud, Multi-cloud systems, Cloud security, Governance, Data protection

Introduction

Hybrid and multi-cloud systems have become central to contemporary information technology because organizations rarely operate in a single, uniform environment anymore. Many institutions combine on-premises infrastructure with cloud services, and many also rely on more than one public cloud provider for strategic, technical, or operational reasons. Microsoft defines hybrid cloud as a combination of on-premises or private infrastructure and public cloud services working together, while multicloud refers to the use of multiple cloud providers at the same time. The same guidance emphasizes that the real challenge is to unify these environments in a secure and well-managed way rather than simply connect them mechanically [1].

This challenge is now recognized at the level of security standards and policy guidance. NIST's Multi-Cloud Security Public Working Group was established specifically to research best practices for securing complex cloud solutions involving multiple service providers and multiple clouds. NIST also notes that organizations adopting such solutions face added security and privacy implementation challenges. This point is important because it shows that hybrid and multi-cloud security is not a minor variation of ordinary cloud administration. It is a separate and more demanding security problem shaped by heterogeneity, shared responsibility, and distributed control [2].

The purpose of this paper is to examine the major security challenges in hybrid and multi-cloud systems. The discussion focuses on identity and access management, data protection and privacy, visibility and monitoring, misconfiguration, governance and compliance, and migration-related risk. The central argument is that the most serious weakness in these environments is

inconsistency. Security controls may exist on paper, and they may even function well within individual platforms, but once they are applied unevenly across several environments, the overall system becomes fragile.

Understanding The Security Context Of Hybrid And Multi-Cloud Systems

To understand why these systems are difficult to secure, it is first necessary to understand why organizations adopt them. Microsoft's guidance identifies several important business drivers for hybrid and multicloud strategies, including vendor flexibility, business unit diversity, compliance and data residency requirements, resilience and disaster recovery, performance optimization, modernization, and the need to eliminate operational silos. These drivers explain why many organizations deliberately accept architectural complexity in exchange for strategic benefits. Hybrid and multi-cloud systems are therefore not accidental or temporary arrangements; in many cases, they are conscious long-term operating models [1].

However, the benefits that make these systems attractive also generate new security pressure. NIST highlights that many organizations diversify their cloud portfolios to incorporate multi-party cloud solutions, but that these solutions also create added security and privacy implementation challenges. In practice, this means that security teams must deal with more identities, more APIs, more network boundaries, more policy frameworks, and more uncertainty about who is responsible for which controls. A system that spans multiple providers or combines cloud and non-cloud infrastructure becomes harder to govern because security is no longer concentrated in one place. Instead, it must be coordinated across several environments that may differ in technology, management style, and operational maturity [2].

This broader context matters because security weaknesses in hybrid and multi-cloud systems are rarely isolated. A problem in one area often affects another. Poor identity governance can increase data exposure. Incomplete visibility can hide configuration drift. Weak governance can undermine compliance. Migration can reintroduce vulnerabilities into supposedly modern environments. For that reason, hybrid and multi-cloud security must be treated as an architectural issue and an organizational issue at the same time.

Identity and Access Management

Identity and access management is one of the most important security challenges in hybrid and multi-cloud systems because access now extends across multiple environments rather than a single internal domain. AWS documentation on IAM best practices recommends that human users access AWS through federation with an identity provider and temporary credentials, that workloads use temporary credentials with IAM roles, and that multi-factor authentication be required where appropriate. AWS also recommends least-privilege permissions, regular review of unused users and roles, and the establishment of permissions guardrails across multiple accounts. These recommendations are directly relevant to hybrid and multi-cloud systems because the number of users, roles, service identities, and trust relationships increases significantly once several environments are involved [3].

In such systems, identity management is not just about who can sign in. It is about maintaining a coherent authorization model across different platforms, teams, and services. One cloud may be tightly controlled through role-based access and short-lived credentials, while another may still depend on static secrets or overly broad permissions. In the same organization, developers may have different levels of access in different clouds, and service accounts may be governed with very different levels of discipline. This creates hidden risk. An account that is too powerful in one environment, or a credential that remains active after it should have been removed, can compromise more than one platform if systems are integrated.

Another challenge is that machine identities now matter as much as human identities. Modern cloud systems rely heavily on automated pipelines, orchestration tools, applications, containers, and serverless components. These entities need permissions to retrieve secrets, call

APIs, move data, or deploy infrastructure. In hybrid and multi-cloud systems, the number of these non-human identities can become very large, and they may exist across several trust boundaries. If organizations cannot see, classify, and govern these identities consistently, their security model becomes fragmented.

For this reason, strong identity governance is foundational. Federation, temporary credentials, least privilege, periodic access review, strict role separation, and consistent deprovisioning are not optional improvements in hybrid and multi-cloud systems. They are basic conditions for controlling the attack surface.

Data Protection and Privacy

Data protection is another central challenge because hybrid and multi-cloud systems rarely keep data in one place. Operational data may be generated on-premises, stored in one cloud, backed up in another, analyzed in a third service, and accessed by applications running in several regions. This movement increases complexity because organizations must control not only storage security but also classification, transfer, access, retention, and privacy handling. Google Cloud documentation states that Sensitive Data Protection helps organizations discover, classify, and de-identify sensitive data inside and outside Google Cloud. This guidance is important because it shows that effective protection begins with understanding what data are sensitive and where those data exist [4].

In practice, the problem is broader than encryption alone. A dataset may be protected while stored in one platform but become more exposed during synchronization, testing, backup, analytics, or migration. The same information can be replicated across accounts, regions, or services for performance and resilience reasons, yet each copy introduces another control problem. Teams must determine who can access the data, whether transfers are secure, how long the data are kept, whether de-identification is necessary, and whether legal or contractual restrictions apply to the location where data are being processed.

Privacy concerns also become more difficult in these systems because different environments may handle metadata, logs, backups, and derived data in different ways. Sensitive information may appear not only in primary storage but also in error logs, telemetry, temporary files, debugging environments, and replicated snapshots. In regulated settings, this matters because an organization may satisfy privacy obligations in one environment while failing to maintain the same standard in another. Data protection therefore becomes a consistency problem rather than a narrow storage problem.

A secure hybrid or multi-cloud architecture must treat data as something that moves through a lifecycle rather than something that simply sits inside a protected storage service. Organizations need visibility into data location, classification of sensitive content, controlled sharing, and disciplined retention practices. Without these, the spread of data across multiple environments creates avoidable exposure.

Visibility, Monitoring, and Incident Awareness

Visibility is one of the most basic requirements of security, yet it is often weaker in hybrid and multi-cloud environments than in simpler architectures. Security teams need to know what assets exist, how those assets are configured, which ones are exposed, whether activity is suspicious, and how incidents develop across multiple environments. Microsoft's documentation on Cloud Security Posture Management states that CSPM provides continuous visibility into the security state of cloud assets and workloads and offers actionable guidance across Azure, AWS, and GCP. This is highly relevant to hybrid and multi-cloud systems because those systems are difficult to secure when visibility is split across different consoles, teams, and tooling models [5].

The absence of strong visibility creates several operational risks. First, organizations may not maintain a reliable and current inventory of resources. Second, logs and alerts may be distributed across different monitoring systems, making it difficult to detect patterns that span

environments. Third, incident response becomes slower because investigators must reconstruct events from incomplete or inconsistent evidence. Fourth, posture management becomes reactive rather than proactive, because security teams discover problems only after exposure has already occurred.

Visibility is especially important in environments that change frequently. Infrastructure-as-code deployments, automated pipelines, temporary environments, and service integration points can create resources faster than traditional review processes can handle. In such conditions, blind spots grow quickly. An organization may think it understands its cloud footprint while in reality it only understands the part that is easiest to monitor. This mismatch between perceived visibility and actual visibility is dangerous because it produces false confidence.

For this reason, hybrid and multi-cloud security depends on unified or at least coordinated monitoring, asset inventory, and posture awareness. Security teams need to see not only individual environments but also the relationships between them. Otherwise, each platform may appear manageable on its own while the overall architecture remains poorly understood.

Misconfiguration and Configuration Drift

Misconfiguration is one of the most common practical causes of cloud exposure, and the risk becomes greater in hybrid and multi-cloud systems because several platforms must be administered together. Azure Policy documentation explains that Azure Policy helps enforce organizational standards and assess compliance at scale. It also states that its compliance dashboard provides an aggregated view of the environment and supports remediation for existing and new resources. This guidance is directly relevant because hybrid and multi-cloud systems tend to drift away from security baselines unless policy enforcement and compliance review are built into daily operations [6].

Configuration drift occurs when standards exist in principle but not in practice. A team may require diagnostic logging, encryption, or network restrictions in one environment but forget to apply equivalent controls in another. One provider may have strict governance templates while another depends more heavily on local team choices. Over time, these differences accumulate. A resource that looks normal from within its own platform may be out of line with the organization's broader security baseline.

The danger is increased by the fact that administrators often carry assumptions from one platform into another. A default setting that is safe in one cloud may be open in another. Terminology can also be misleading. Similar words may describe controls that work differently across services and providers. In hybrid systems, configuration complexity is further increased by the need to integrate cloud settings with on-premises infrastructure, legacy applications, and transitional architectures. Under delivery pressure, teams may focus on availability or speed and leave standardization for later. That is exactly how drift begins.

Misconfiguration should therefore not be treated merely as a human mistake. In hybrid and multi-cloud systems, it is a structural risk generated by diversity, scale, and uneven governance. Preventing it requires baseline controls, reusable templates, posture monitoring, remediation workflows, and a clear definition of what "secure by default" means across the entire environment.

Governance, Compliance, and Organizational Control

Governance is one of the most important and most underestimated security challenges in hybrid and multi-cloud systems. Technical controls may exist, but without governance there is no reliable way to define policy, assign ownership, handle exceptions, or verify that security requirements are actually being enforced. Google Cloud states that the Organization Policy Service gives organizations centralized and programmatic control over Google Cloud resources and allows constraints to be configured across the entire resource hierarchy. AWS Organizations similarly states that it helps centrally manage and govern environments as AWS resources scale, allowing

policies to be applied and workflows to be organized across accounts. Together, these official sources show that cloud security at scale depends on centralized governance rather than isolated local decisions [7][8].

Compliance is closely tied to governance. Regulations, contractual obligations, internal policies, and industry expectations do not disappear just because systems are distributed across several providers. In fact, distributed operation makes them harder to satisfy consistently. If access approvals, audit logs, retention controls, and data placement rules are handled differently across environments, then compliance becomes difficult both to achieve and to demonstrate. This is especially true when different teams manage different parts of the architecture with different tools and review processes.

Governance also matters because shared responsibility becomes more complex in hybrid and multi-cloud systems. Each provider defines part of the security model, but the customer remains responsible for configuring services correctly, protecting data, managing identities, and enforcing internal standards. Once multiple providers and on-premises components are involved, the number of responsibility boundaries increases. Assumptions that may already be risky in one cloud become even riskier when repeated across several environments.

For this reason, governance must be treated as operational control, not just documentation. Effective governance requires clear policy, ownership, escalation paths, exception handling, review cycles, and coordination across teams. Without that structure, even a technically advanced environment can become insecure simply because nobody governs it coherently.

Migration And Transitional Security Risk

Migration is often discussed as a technical or project-management activity, but in hybrid and multi-cloud systems it is also a security issue. Workloads and data are frequently moved between on-premises infrastructure and public clouds, or between one cloud provider and another. During these transitions, systems may operate in partially migrated states, with dependencies spread across old and new environments at the same time. This creates a period of elevated risk because the architecture is changing while business operations continue.

Migration can expose weaknesses in several ways. Sensitive data may move through temporary pathways that were not designed for long-term secure operation. Temporary accounts or elevated privileges may remain active after a migration is completed. Logging, monitoring, or backup controls may not follow workloads cleanly into the target environment. Legacy assumptions about trust boundaries may persist even when the workload now runs in a very different context. If migration is rushed, security validation is often treated as a final step instead of a continuous requirement.

There is also a governance dimension to migration. When teams move services under schedule pressure, they may prioritize availability and functionality over standardization and hardening. As a result, the migrated environment may inherit older weaknesses while also gaining new ones. In hybrid settings, this is especially dangerous because the organization may keep part of the workload on-premises and move only another part into the cloud, creating a split trust model that is harder to reason about and harder to defend.

For that reason, migration should be treated as a controlled security transition rather than a purely technical relocation. Access changes, data movement, dependency mapping, rollback conditions, and post-migration validation all need explicit attention. Otherwise, the process of modernization can become a source of insecurity rather than an improvement.

Conclusion

Hybrid and multi-cloud systems offer flexibility, resilience, provider diversity, and support for varied business requirements. At the same time, they are more difficult to secure than single-environment architectures because they distribute identities, data, workloads, and control mechanisms across different platforms and teams. The main security problem in these

environments is not simply that there are more components. It is that security must remain coherent even when technology, operations, and responsibility are fragmented.

This paper has argued that the most serious security challenges in hybrid and multi-cloud systems involve identity and access management, data protection and privacy, visibility and monitoring, misconfiguration, governance and compliance, and migration-related risk. These are interconnected rather than independent issues. Weak identity governance can increase exposure to data loss. Incomplete visibility can hide drift and delay incident response. Weak governance can undermine compliance and make migrations less secure.

The central lesson is that consistency matters more than isolated strength. An organization can deploy excellent controls in one platform and still remain vulnerable if those controls are absent or poorly enforced in another. Effective hybrid and multi-cloud security therefore requires unified governance, strong visibility, disciplined access control, careful data handling, and continuous operational oversight across the whole environment. Without that consistency, complexity itself becomes a security risk.

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Blokçeyn Texnologiyasının İqtisadiyyat və İdarəetmədə Tətbiqi

Cəfərova İlahə

Magistrant

Xülasə

Bu məqalədə blokçeyn texnologiyasının əsas prinsipləri, potensialı və iqtisadiyyat və idarəetmədə tətbiq sahələri ətraflı təhlil edilmişdir. Texnologiyanın inkişaf tarixindən başlayaraq, onun maliyyə sektoru, təchizat zənciri, səhiyyə, dövlət idarəçiliyindəki konkret tətbiqləri araşdırılmışdır.

Məqalədə maliyyə sektorunda kriptovalyutalar vasitəsilə yaradılmış inqilabdan bəhs edilmiş, eyni zamanda mərkəzləşdirilməmiş maliyyə (DeFi) xidmətlərinin ənənəvi bank sistemlərinə alternativ kimi inkişafı analiz edilmişdir. Təchizat zənciri idarəetməsində blokçeyn-in məhsul izlənməsini asanlaşdırması və şəffaflığı artırması xüsusi nümunələrlə göstərilmişdir. Bundan əlavə, blokçeyn texnologiyasının tibbi qeydlərin qorunması və təhlükəsiz saxlanması sahəsindəki tətbiqi və dövlət idarəçiliyində şəffaf seçki sistemlərinin yaradılmasında rolu təhlil edilmişdir.

Məqalənin digər mühüm hissəsi Azərbaycanda blokçeyn texnologiyasının mövcud vəziyyətinə və istifadəsinə həsr olunmuşdur. Bu bölmədə ölkədə kriptovalyutaların istifadəsi, dövlət xidmətlərində blokçeyn texnologiyasının tətbiqi üçün aparılan ilkin addımlar və bu texnologiyanın iqtisadiyyata potensial təsiri müzakirə edilmişdir. Xüsusilə, rəqəmsal mülkiyyət hüquqlarının qorunması və yerli biznesdə blokçeyn-in tətbiq imkanları üzərində dayanılmışdır.

Bu təhlillər nəticəsində, məqalə oxuculara blokçeyn-in təkcə indiki deyil, həm də gələcəkdəki potensialını dərk etməyə imkan verir və onun müxtəlif sahələrdə necə tətbiq edilə biləcəyini geniş şəkildə izah edir.

Açar sözlər: *Blokçeyn Texnologiyası, Kriptovalyutalar, Azərbaycanda blokçeyn texnologiyası, Rəqəmsal təhlükəsizlik, Təchizat zənciri*

Abstract

This article provides an in-depth analysis of the fundamental principles, potential, and application areas of blockchain technology in economics and public administration. Beginning with the history and evolution of the technology, the study examines its concrete use cases in the financial sector, supply chain management, healthcare, and government services.

The article highlights the transformative role of cryptocurrencies in the financial industry and analyzes the development of decentralized finance (DeFi) as an alternative to traditional banking systems. Additionally, the study explores the use of blockchain for securing and preserving medical records and its role in enabling transparent and reliable electronic voting systems.

Another key section focuses on the current state and adoption of blockchain technology in Azerbaijan. This includes an overview of cryptocurrency usage in the country, initial governmental steps toward integrating blockchain into public services, and the technology's potential impact on the national economy. Special emphasis is placed on the protection of digital property rights and the possible integration of blockchain solutions into local businesses.

Overall, the article helps readers understand both the current and future potential of blockchain technology and explains how it can be effectively applied across various domains.

Keywords: Blockchain Technology, Cryptocurrencies, Blockchain technology in Azerbaijan, Digital Security, Supply Chain

Giriş

Son illər texnologiyanın inkişafı yeni, inqilabi sistemlərin ortaya çıxmasına səbəb olmuşdur. Bu sistemlərdən biri də blokçeyn texnologiyasıdır. Ənənəvi olaraq kriptovalyutalarla əlaqələndirilsə də, blokçeyn-in tətbiq sahələri bununla məhdudlaşmır. Bu texnologiya mərkəzləşdirilməmiş, şəffaf və təhlükəsiz məlumat idarəetmə sistemi təqdim etməklə müasir biznes mühitində əhəmiyyətli rol oynamaqdadır.

Blokçeyn, bir çox sənaye sahəsində – səhiyyə, təchizat zənciri, təhsil, maliyyə xidmətləri və hətta dövlət idarəçiliyi – yeni imkanlar yaratmışdır. Təchizat zəncirində məhsul izlənməsi, səhiyyədə pasiyent məlumatlarının qorunması və maliyyə sahəsində əməliyyatların daha sürətli və şəffaf şəkildə aparılması bu texnologiyanın güclü tərəflərindəndir.

Ancaq bu inqilabi texnologiyanın yayılması ilə müəyyən çağırışlar da yaranır. Texnologiyanın mürəkkəbliyi, enerji istehlakı və hüquqi tənzimləmələrlə bağlı məsələlər blokçeyn-in tam potensialını reallaşdırmaq üçün həllini gözləyən problemlər sırasındadır. Bu məqalə, blokçeyn-in əsas anlayışlarını, müasir tətbiq sahələrini, mövcud problemlərini və gələcək perspektivlərini araşdıraraq bu texnologiyanın geniş istifadə imkanlarını işıqlandıracaqdır.

Həmçinin, blokçeyn-in təsiri yalnız texnologiya sahəsi ilə məhdudlaşmır; o, sosial, iqtisadi və hüquqi sferalarda da yeni yanaşmaların tətbiqini tələb edir. Bu baxımdan, blokçeyn texnologiyası gələcəkdə daha geniş tətbiq sahələri və innovativ həllər təqdim etməyə hazırdır.

Bu məqalədə, blokçeyn-in əsas xüsusiyyətləri, onun müxtəlif sənaye sahələrində tətbiq nümunələri və gələcəkdə gözlənilən inkişaf istiqamətləri nəzərdən keçiriləcəkdir. Bu yanaşma ilə blokçeyn-in cəmiyyətə və iş dünyasına nə dərəcədə transformativ təsir göstərdiyi aydın olacaq.

Blokçeyn texnologiyasının əsasları

Blokçeyn texnologiyası müasir rəqəmsal transformasiyanın mərkəzində dayanır və onun əsas funksionallığını anlamaq texnologiyanın geniş tətbiqlərini dərk etmək üçün vacibdir. Blokçeyn mərkəzləşdirilməmiş, paylanmış bir sistemdir ki, burada məlumatlar ardıcıl bloklar şəklində saxlanılır və dəyişməz şəkildə qeyd edilir. Hər bir blok özündən əvvəlki blokla kriptografik şəkildə əlaqələndirilir, bu da məlumatın dəyişdirilməsini və ya silinməsinə demək olar ki, mümkünsüz edir. [5, 7]

Blokçeyn-in Əsas Prinsipləri

Blokçeyn-in işləmə prinsipləri aşağıdakı xüsusiyyətlərlə təyin edilir:

1. **Mərkəzləşdirilməmiş:** Blokçeyn mərkəzləşdirilmiş serverlərdən asılı olmayan bir texnologiyadır. Bu, məlumatların fərqli yerlərdə saxlanılaraq daha təhlükəsiz idarə edilməsinə imkan yaradır.
2. **Kriptografik Təhlükəsizlik:** Hər bir blokda saxlanılan məlumatlar kriptografik üsullarla qorunur. Bu, məlumatların dəyişdirilməsinə və ya silinməsinə mane olur.
3. **Daha sürətli hesablama:** Blokçeyn texnologiyası əməliyyatların sürətli və avtomatlaşdırılmış şəkildə aparılmasına imkan verir. Bu, ənənəvi üsullarla müqayisədə zamana və resurslara qənaət edir.
4. **Geri dönməz və yoxlanıla bilən:** Əməliyyatlar bir dəfə həyata keçirildikdən sonra geri qaytarıla bilmir. Bu, sistemdə şəffaflıq və izləniləbilərlik yaradır.
5. **Dəyişməz və təkrarlana bilməz:** Blokçeynə daxil olan məlumatlar bir daha dəyişdirilə bilməz. Bu xüsusiyyət məlumatların tam təhlükəsizliyini təmin edir.
6. **Şəffaf və sübut oluna bilən:** Blokçeyndəki məlumatlar bütün iştirakçılar üçün şəffafdır. Hər bir əməliyyatın izi sübut olaraq saxlanılır.
7. **Etibarlı əməliyyat:** Hər bir əməliyyat şəbəkə tərəfindən təsdiqlənir və dəyişdirilə bilmir. Bu, fırıldaqçılıq ehtimalını azaldır və etibarını artırır.
8. **Rəqəmsal kitab:** Blokçeyn rəqəmsal əməliyyatların qeyd edildiyi bir kitabə rolunu oynayır. Bu kitab məlumatların dəyişdirilmədən və təhlükəsiz saxlanmasını təmin edir.
9. **Paylanmış Şəbəkə (Distributed Ledger):** Blokçeyn-də bütün məlumatlar şəbəkə iştirakçıları

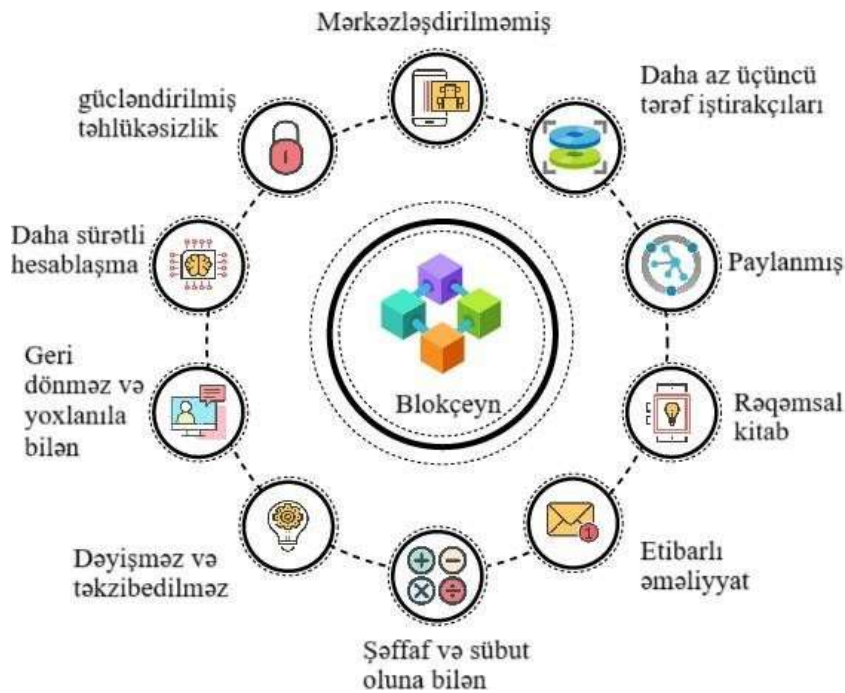
arasında paylanır. Bu, mərkəzləşdirilmiş serverlərə ehtiyacı aradan qaldırır və məlumatların şəffaf şəkildə saxlanmasını təmin edir.

10. **Daha az üçüncü tərəf iştirakçıları:** Blokçeyn vasitəsilə əməliyyatlar birbaşa iştirakçılar arasında həyata keçirilir. Beləliklə, vasitəçilərə ehtiyac qalmır və xərclər azalır. [5, 7, 8, 9, 11]

11. Blokçeyn-in Strukturu

Blokçeyn, əsasən üç hissədən ibarətdir:

- **Bloklar:** Hər bir blokda əməliyyatlar və əvvəlki blokun hash kodu saxlanılır.
- **Şəbəkə Nodları:** Şəbəkənin fərdi iştirakçılarıdır və blokların doğruluğunu təsdiq edirlər.
- **Hash Alqoritmləri:** Blokların bir-birinə təhlükəsiz şəkildə bağlanmasını təmin edir. [1, 5, 7]



Şəkil 1. Blokçeyn Texnologiyasının Əsas Prinsipləri [8]

Blokçeyn Texnologiyasının Tipləri

Blokçeyn texnologiyası dörd əsas tipə bölünür və onlar idarəetmə və əlçatanlıq baxımından fərqlənir: ictimai blokçeyn tam açıq olub heç bir mərkəzi qurum tərəfindən idarə olunmur və hər kəsin qoşula bildiyi şəffaf sistemdir; buna nümunə olaraq Bitcoin və Ethereum göstərilə bilər. Konsorsium blokçeyn bir neçə təşkilat tərəfindən birgə idarə olunur və yalnız müəyyən qurumların iştirakı ilə fəaliyyət göstərir. Hibrid blokçeyn ictimai və özəl sistemlərin xüsusiyyətlərini birləşdirərək bəzi məlumatları açıq, bəzilərini isə məxfi saxlayır və əsasən şirkətlər və dövlət qurumları tərəfindən istifadə olunur. Özəl blokçeyn isə qapalı sistem olub yalnız icazə verilmiş şəxslərin daxil ola bildiyi, yüksək məxfilik və nəzarət tələb edən mühitdə tətbiq edilir; ümumilikdə bu tipləri anlamaq blokçeyn texnologiyasının işləmə prinsiplərini və tətbiq sahələrini daha yaxşı dərk etməyə imkan verir. [2, 9, 11]

Blokçeyn Texnologiyasının Müasir Tətbiq Sahələri

Blokçeyn texnologiyası yalnız kriptovalyutaların əsasını təşkil etməklə məhdudlaşmır. Bu texnologiyanın müasir iqtisadiyyatda və cəmiyyətdə müxtəlif sahələrdə tətbiqi sürətlə genişlənir. Bu bölmədə blokçeyn-in istifadə edildiyi əsas sahələr və onun təsiri müzakirə ediləcəkdir.

Maliyyə Sektoru və Kriptovalyutalar

Maliyyə sahəsi blokçeyn texnologiyasının ən erkən tətbiq sahələrindən biridir. Bitcoin və Ethereum kimi kriptovalyutalar bu texnologiyanın ilk nümunələridir. Blokçeyn, maliyyə

əməliyyatlarını vasitəçilər olmadan həyata keçirməyə imkan verir. Bununla yanaşı, mərkəzləşdirilməmiş maliyyə (DeFi) xidmətləri vasitəsilə kreditlər, sığorta və investisiyalar kimi ənənəvi bank xidmətləri rəqəmsallaşdırılmışdır. [4,6]

Təchizat Zənciri İdarəetməsi

Təchizat zənciri idarəetməsində blokçeyn texnologiyasının tətbiqi məhsulların izlənməsi və şəffaflığın təmin edilməsi sahəsində böyük üstünlüklər təqdim edir. Blokçeyn, məhsulun haradan gəldiyini, hansı şərtlərdə istehsal edildiyini və kimlər tərəfindən emal edildiyini izləməyə imkan verir.

Bu xüsusilə qida sənayesində əhəmiyyətli bir faktordur. Məsələn, IBM-in "Food Trust" platforması vasitəsilə qida məhsullarının izlənməsi artırılmışdır. Bu yanaşma həm istehlakçıların təhlükəsizliyini təmin edir, həm də saxta məhsulların qarşısını alır. [6]

Səhiyyə və Elektron Tibbi Qeydlər

Blokçeyn, pasiyentin məlumatlarının qorunması və səhiyyə xidmətlərinin optimallaşdırılması üçün effektiv bir texnologiya təklif edir. Elektron tibbi qeydlər blokçeyn vasitəsilə təhlükəsiz saxlanıla və yalnız icazəsi olan şəxslər tərəfindən əldə edilə bilər. [3]

Dövlət İdarəçiliyi və Seçki Sistemləri

Blokçeyn texnologiyası dövlət idarəçiliyində şəffaflıq və etibarlılığı artırmaq üçün istifadə olunur. Seçkilərin mərkəzləşdirilməmiş şəbəkələrdə keçirilməsi saxtakarlıq ehtimalını azaldır. Estoniya hökuməti blokçeyn əsaslı elektron səsvermə sistemini tətbiq edən ilk ölkələrdən biri olmuşdur. Bu sistem, seçicilərə səs vermək üçün təhlükəsiz və şəffaf platforma təmin edir. [4]

NFT və Rəqəmsal İncəsənət

Blokçeyn texnologiyası NFT-lər (non-fungible tokens) vasitəsilə rəqəmsal incəsənət və əmlakın unikal şəkildə saxlanmasını və satılmasını təmin edir. NFT-lər rəqəmsal mülkiyyət hüququnu təsdiq edən sənədlər kimi çıxış edir və rəssamların işlərini təhlükəsiz və şəffaf şəkildə bazara çıxarmasına imkan yaradır. [3]

Təhsil və Sertifikatlaşdırma

Blokçeyn texnologiyası təhsil sektorunda saxta sertifikatların qarşısını almaq və akademik nailiyyətlərin şəffaf şəkildə izlənməsini təmin etmək üçün istifadə olunur. Universitetlər və təhsil müəssisələri blokçeyn-də sertifikatlar yaratmaqla saxtakarlığın qarşısını alır və işəgötürənlər üçün yoxlama prosesini asanlaşdırır. [6]

Azərbaycanda blokçeynin tətbiqi və inkişafı

Azərbaycanda blokçeyn texnologiyasının tətbiqi hələ tam inkişaf etməyib, amma bir çox sektorda araşdırmalar və pilot layihələr həyata keçirilir. Bu texnologiya əsasən dövlət xidmətləri, maliyyə sektoru, kənd təsərrüfatı sahələrində istifadə olunur.

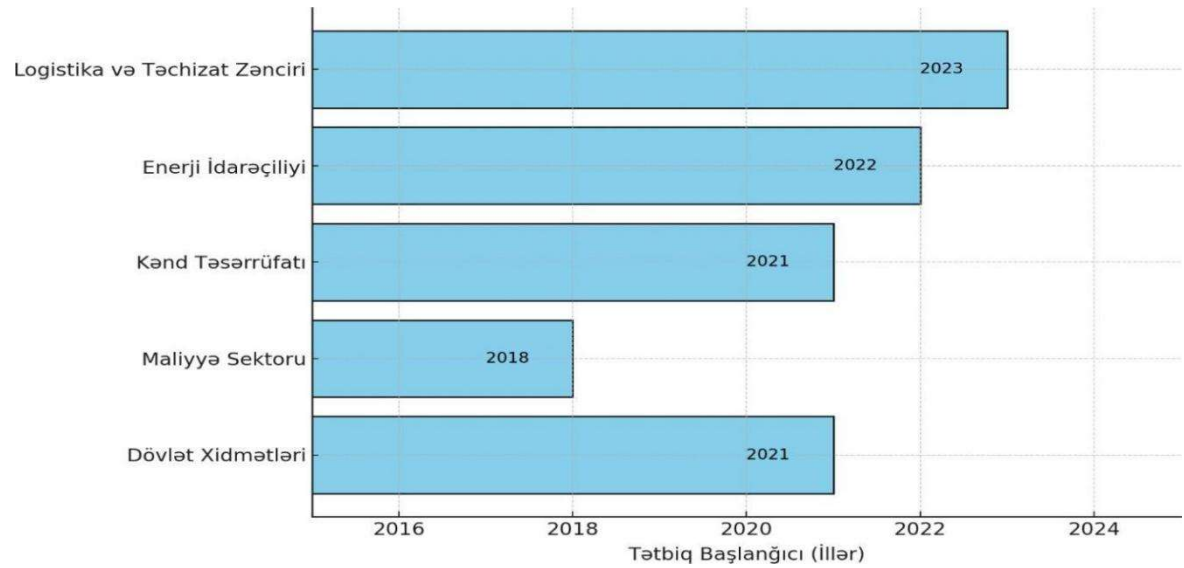
Dövlət xidmətlərində blokçeyn şəffaflıq və təhlükəsizlik təmin edərək, məsələn, şəxsiyyətin idarə edilməsi, səsvermə və ictimai qeydlər kimi sahələrdə tətbiq oluna bilər. Eyni zamanda, maliyyə sektorunda bu texnologiya daha sürətli və sərfəli pul köçürmələri, eləcə də ağıllı müqavilələrlə əməliyyatların avtomatlaşdırılmasına imkan yaradır.

Kənd təsərrüfatında isə, BMT-nin dəstəyi ilə blokçeyn, toxum istehsalçıları və məhsul sertifikatlaşdırma proseslərini şəffaflaşdırmaq məqsədilə istifadə edilir. Bu sahədə tətbiq edilən platformalar vasitəsilə, məhsulların marşrutları, keyfiyyəti və qiymətləri izlənə bilər. Həmçinin, səhiyyə sahəsində elektron sağlamlıq qeydləri və müalicə məlumatlarının təhlükəsizliyi üçün də blokçeyn tətbiq oluna bilər. [10]

Sahə	İstifadə Nümunələri	Əhəmiyyəti
Dövlət Xidmətləri	Şəxsiyyətin idarə edilməsi, səsvermə, ictimai qeydlər	Şəffaflıq, təhlükəsizlik və səmərəliliyi artırmaq
Maliyyə Sektoru	Rəqəmsal valyutalar, pul köçürmələri, smart müqavilələr	Maliyyə əməliyyatlarını sürətləndirmək, bank əməliyyatlarının təkmilləşdirilməsi
Kənd Təsərrüfatı	Toxum sertifikatlaşdırması, məhsul izləmə	Keyfiyyətin təmin olunması və istehlakçı etibarının artırılması
Enerji İdarəçiliyi	Enerji ticarəti, smart müqavilələrlə enerji paylanması	Enerji bazarlarında şəffaflıq və əməliyyatların asanlaşdırılması
Logistika və Təchizat Zənciri	Əmtəə izlənməsi, saxlama və daşınma məlumatlarının şəffaflaşdırılması	Təchizat zəncirində şəffaflıq və effektivlik təmin etmək

Cədvəl 1. Azərbaycanada Blokçeyn Texnologiyasının Sahələr üzrə Tətbiqi və Faydaları (müəllif tərəfindən hazırlanıb)

Aşağıda verilən qrafik, blokçeyn texnologiyasının müxtəlif sahələrdə tətbiqinin başlanğıc illərini göstərir. Hər bir sahənin tətbiqinə başlama tarixi ilə əlaqədar müxtəlif illər göstərilib. Məsələn, Dövlət Xidmətləri sahəsində blokçeyn texnologiyası 2021-ci ildən istifadəyə verilməyə başlanıb, Maliyyə Sektoru isə 2018-ci ildən bu texnologiyadan faydalanmağa başlayıb. Qrafikdə, Kənd Təsərrüfatı, Enerji İdarəçiliyi və Logistika və Təchizat Zənciri sahələri də göstərilib. [10]



Qrafik 1. Blokçeyn texnologiyasının Azərbaycanada tətbiqinin başlanma illəri (müəllif tərəfindən hazırlanıb)

Nəticə

Blokçeyn texnologiyası son illərdə sürətlə inkişaf edərək müxtəlif sahələrdə tətbiq tapmağa başlamışdır. Ənənəvi maliyyə sistemlərindən tutmuş, səhiyyə, dövlət idarəçiliyi, təchizat zənciri, təhsil və rəqəmsal sənətə qədər geniş tətbiq sahələri blokçeyn-in potensialını nümayiş etdirir. Kriptovalyutaların yaradılması ilə blokçeyn, ilk növbədə maliyyə sektorunda inqilab yaratdı. Həmçinin, mərkəzləşdirilməmiş maliyyə (DeFi) xidmətləri, bank sistemlərini tərsinə çevirərək əməliyyatların daha sürətli və daha ucuz olmasını təmin etdi.

Təchizat zənciri və səhiyyə kimi sahələrdə blokçeyn-in tətbiqi, məhsulların izlənməsi və tibbi məlumatların qorunması sahəsində müsbət nəticələr vermişdir. Blokçeyn texnologiyası, saxtakarlığın qarşısını almağa və şəffaflıq yaratmağa kömək edir, bu da istehlakçıların etibarını artırır. Digər tərəfdən, rəqəmsal incəsənət və NFT-lər blokçeyn-in yeni tətbiq sahələrini açmış və sənətçilər üçün mülkiyyət hüquqlarını qorumağın yeni yollarını təqdim etmişdir.

Blokçeyn texnologiyasının gələcəkdə daha çox sahədə tətbiq olunması və inkişaf etməsi gözlənilir. Məsələn, təhsil sahəsində diplomların və sertifikatların blokçeyn vasitəsilə verilərək saxtakarlığa qarşı mübarizə aparılması, gələcəkdə daha çox təhsil müəssisələri tərəfindən tətbiq edilə bilər. Həmçinin, blokçeyn, dövlət idarəçiliyində şəffaflıq və etibar yaratmağa kömək edəcək və səsvermə sistemlərinin etibarlılığını artıracaq.

Bundan əlavə, blokçeyn texnologiyasının təkmilləşdirilməsi və post-kvant təhlükəsizlik standartlarına uyğunlaşdırılması ilə bağlı araşdırmalar davam edir. Bu, gələcəkdə blokçeyn-in daha geniş tətbiq sahələrində istifadə edilməsinə imkan yaradacaq və onun gücünü daha da artıracaqdır. Ümumilikdə, blokçeyn texnologiyasının tətbiqləri dünyanı daha açıq, şəffaf və etibarlı bir yerə çevirməyə istiqamətlənmişdir, və bu inkişaf daha da genişlənəcəkdir.

Bu nəticələrdən çıxarılan əsas məqam blokçeyn texnologiyasının yalnız bir neçə illik inkişaf dövründə əldə etdiyi uğurların dünya iqtisadiyyatında və cəmiyyətində əhəmiyyətli dəyişikliklər yaratmağa başladığıdır. Gələcəkdə blokçeyn-in tətbiqi və təkamülü yeni iş imkanları və inkişaf sahələri açacaqdır.

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UDC 622.276.6

DRILLING OF OIL AND GAS WELLS IN UNSTABLE CLAY FORMATIONS

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Introduction. During drilling operations in oil and gas fields, a long-term, stable, and well-isolated channel must be created to connect the productive formation with the surface. Drilling and cementing fluids play a crucial role during well construction. Not only the efficiency of drilling operations, but also the service life of the well depends on the ability of these fluids to perform their functions under various geological and technical conditions. The commonly used terms drilling fluid, circulating fluid, or cement slurry do not fully reflect the physicochemical nature of these systems; their usage is largely based on industry tradition. In terms of composition, these systems should be classified as complex polymineral dispersions stabilized by surfactants (surface-active agents) [1].

Despite the large number of studies proposing formulations for drilling fluids based on modern technologies, there remain significant challenges when drilling deep wells. These challenges are associated with the need to adapt existing technologies to the lithological, reservoir, and thermobaric characteristics specific to the drilling region. Deep formations characterized by abnormal (low or high) formation pressures exhibit several distinct features. In the conditions typical of Kazakhstan, unstable clay sediments are highly hydrophilic. As a result, their interaction with the aqueous phase of drilling fluids and the effect of hydrostatic pressure lead to swelling caused by hydrodynamic pressure (up to 20%) and physicochemical processes occurring in the annular space (up to 64%).

One of the main challenges in well construction in the oil fields of the South Torgai Basin is lost circulation. The costs associated with combating this problem account for more than 75% of total expenses. Annually, 9–11% of total drilling time is spent addressing such complications, which negatively affects the technical and economic performance of drilling operations. Lost circulation occurs when drilling or cementing fluids flow from the wellbore into permeable formations due to excess hydrostatic or hydrodynamic pressure relative to formation pressure. This leads to fluid losses, inability to perform certain geophysical surveys, and increased repair time [2]. Fluid losses may also occur due to the presence of fractures, caverns, and channels in the formation, or due to insufficient rock strength under fluid column pressure, which may result in hydraulic fracturing.

Absorbing formations may be porous, cavernous, or fractured. Porous formations include sand and siltstone with intergranular porosity; fractured formations contain cracks and fracture permeability; cavernous formations are characterized by microcracks of varying apertures. The permeability of sandy-clay formations depends on pore size, which can be classified as subcapillary (≤ 0.0002 mm), capillary (0.0002 – 0.508 mm), and supercapillary (>0.508 mm). Fluid movement in

subcapillary pores is extremely slow, in capillary pores it occurs only when external forces exceed capillary forces, and in supercapillary pores fluid flows freely.

In fine- and medium-grained fractured sandstones and siltstones, fluid losses are typically minimal due to the formation of a low-permeability filter cake. In coarse-grained sandstones, filtration occurs at a higher rate. Most commonly, losses occur in carbonate rocks (limestones). The intensity of fluid loss is influenced by tectonic disturbances (fracture zones) intersected by the wellbore and by intrusive contacts within limestones, where weakened zones are formed [3].

To prevent lost circulation, methods aimed at increasing fracture resistance are applied. These involve injecting lost circulation materials into newly formed or existing fractures to seal and bridge them, thereby preventing fracture propagation and stopping fluid loss.

Currently, drilling fluids with enhanced water-retention capacity due to polymer additives are widely used to reduce complication intensity. In southern Kazakhstan oil and gas fields, the most common problems include lost circulation, sloughing, and collapse of clay formations, all associated with wellbore instability.

The aim of this study is to develop a drilling fluid composition with specified functional properties for oil and gas well drilling. The proposed fluid is characterized by optimized density and viscosity, ensuring effective circulation and the formation of a stable filter cake on the wellbore wall. A reduction in fluid loss is achieved by introducing a polymer reagent based on polyacrylamide modified with soapstock, as well as fatty acid salts, natural resin, and crushed cotton fiber.

Materials and Methods. The main component of clay-based drilling fluid is bentonite. When hydrated, natural clay minerals can swell up to 15 times their original volume, forming a dense, gel-like mass. Local bentonite from the Darbaza deposit (Turkistan region) is an effective structure-forming additive, as its properties are enhanced when combined with modified polymer additives. The composition of the drilling fluid includes: modified polyacrylamide-based polymer additive (MPAA), bentonite clay (BG), crushed cotton fiber (length 2–5 mm), water.

In this study, low-clay drilling fluids containing polyacrylamide modified with fatty acid salts of gossypol resin were developed. Upon penetration into the formation, the polymer swells, reducing fluid loss. Bentonite serves as a structure-forming agent, while crushed cotton fiber enhances filter cake quality and reduces filtration rate. Soda ash is added to regulate calcium ion concentration [4–5]. During circulation and interaction with formations, polyacrylamide reduces the rate of fluid penetration into the rock, thereby decreasing the volume of losses. As circulation continues, the concentration of cotton fiber decreases due to partial deposition in the filter cake. Therefore, periodic adjustment of the drilling fluid is required to restore the initial concentration of fiber, as well as polymer and bentonite content. The saponified fraction (fatty acid salts and gossypolates), together with polyacrylamide, improves permeability control and imparts additional anticorrosion and lubricating properties to the drilling fluid [6–8].

Results and Discussion. The experimental results presented in table 1 demonstrate that modified polyacrylamide of different compositions has varying effects on the filtration and rheological properties of the model drilling fluid.

Table 1 – Effect of modified polyacrylamide of different compositions on the filtration and rheological properties of a model drilling fluid

No	Drilling Fluid Composition	Density , kg/m ³	Apparent Viscosity, s	Fluid Loss, cm ³ /30 min	Filter Cake Thickness, mm	pH
1.	Initial solution: 1000 ml water + 4g NaOH + 4g Na ₂ CO ₃ + 100g Darbaza bentonite	1030	14	6,0	5	10,0
2.	Initial solution + 0.1% MPAA + 0.03% CCF	1040	16	5,5	4	11
3.	Initial solution +0,5% MPAA+0,05% CCF	1030	18	5,0	4	11
4.	Initial solution +1% MPAA+0,1% CCF	1030	19	4,0	3	11,0
5.	Initial solution +1,25% MPAA+0,5% CCF	1030	22	4,5	3,5	11,0

Figures 1 and 2 show the fluid loss and apparent viscosity values of clay-based drilling fluids formulated with modified polyacrylamide, as a function of reagent concentration.

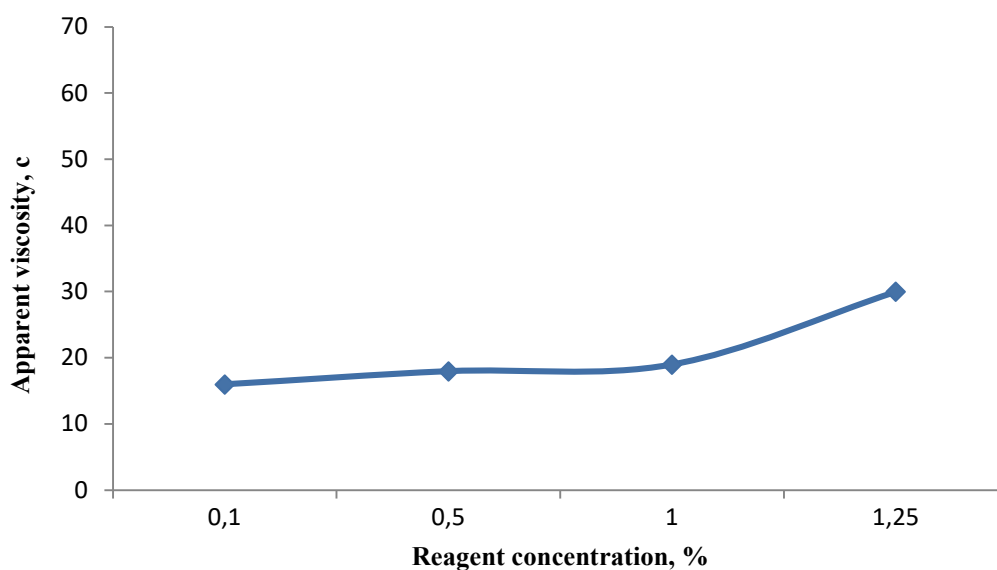


Figure 2 – Dependence of the apparent viscosity of the drilling fluid on the concentration of the new MPAA reagent in its composition

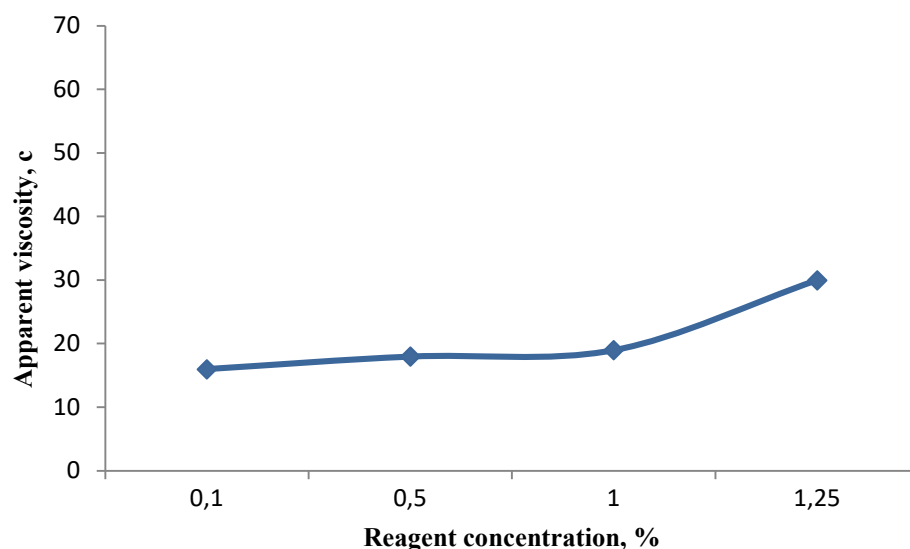


Figure 3 – Dependence of the fluid loss rate of the drilling fluid on the concentration of the new MPAA reagent in its composition

The data obtained from the above dependencies indicate that the variation in fluid loss and apparent viscosity of clay-based drilling fluids, as a function of the concentration of the studied reagent, exhibits an almost linear relationship. Increasing the bentonite clay content up to 10% leads to an increase in viscosity while simultaneously reducing fluid loss, which contributes to the formation of a high-quality filter cake on the wellbore wall.

Among the investigated compositions, formulation No. 4 (Table 1) was selected as the optimal solution, as it demonstrated the best performance in terms of key parameters. The proposed optimal drilling fluid (No. 4) ensures the formation of a high-quality filter cake, reduces drilling fluid losses, minimizes fluid loss, and maintains stable viscosity values.

The use of composite chemical reagents based on locally sourced modified polymer materials improves the stability of drilling fluids during well drilling. Due to their good water solubility, as well as the presence of fatty acid salts of saponified gossypol resin and insoluble fibrous materials, these reagents enhance the structural strength of the drilling fluid, promote hydrophobicity, and provide improved lubricating properties. In addition, effective physicochemical interaction between components contributes to a reduction in filtration rate and filter cake thickness, thereby exerting a strong stabilizing effect on the drilling fluid properties.

Conclusions. Thus, the results of studying the properties of drilling fluids with the addition of a new reagent based on saponified gossypol resin demonstrate improved filtration characteristics. This confirms that the developed additive meets the requirements for drilling fluids aimed at reducing fluid loss and improving performance during drilling operations.

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Modeling and Development of Ontology-Based Information System to Support Medical Activity

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Abstract

Medical information systems face significant challenges in semantic interoperability, knowledge reuse, and intelligent decision support. This paper presents the design and experimental evaluation of an ontology-based information system (OBIS) for supporting clinical activity. We construct a custom dataset of 100 patient records encompassing 24 clinical attributes, spanning 13 ontology disease classes and 19 medical departments. The proposed system integrates ICD-10, SNOMED CT, and LOINC terminologies within a unified ontological framework modeled using OWL 2 and SPARQL-based inference. Experimental results demonstrate a mean ontology inference accuracy of 89.57% and a semantic similarity score of 85.34%, with a mean query response time of 125.77 ms. A Random Forest classifier achieves the highest classification performance with 45.0% accuracy on the 13-class task. Comparative evaluation shows the proposed system surpasses traditional SQL databases, rule-based expert systems, and keyword-search IS by 17–24 percentage points in query accuracy. These findings validate the feasibility of ontology-driven architecture for enhancing semantic search, automated clinical coding, and decision support in healthcare information systems.

Keywords: *medical ontology, OWL 2, SNOMED CT, ICD-10, clinical information system, semantic interoperability, SPARQL, knowledge representation*

1. Introduction

The digitalization of healthcare has produced vast quantities of clinical data stored in heterogeneous systems — electronic health records (EHRs), laboratory information systems, PACS, and prescription databases. A fundamental challenge in clinical informatics is semantic interoperability: enabling different systems to share and understand data without loss of meaning [1]. Traditional relational databases and procedural rule engines have proven insufficient because they lack formal knowledge representation capable of supporting inference and semantic querying.

Ontologies offer a principled solution by providing a shared formal vocabulary with well-defined relationships and axioms [2]. When combined with description logics (DLs) and semantic web standards such as OWL 2 and SPARQL, ontologies enable automated reasoning, concept subsumption, and semantic similarity computation — capabilities essential for clinical decision support, cohort identification, and adverse event detection.

In this paper, we present the full modeling pipeline and empirical evaluation of an ontology-based information system (OBIS) designed for a multi-departmental hospital setting. Our contributions are: (i) a novel clinical dataset of 100 annotated patient records with ontology class assignments; (ii) a multi-standard ontological model integrating ICD-10, SNOMED CT, and LOINC; (iii) a semantic query engine benchmarked against three baseline IS architectures; and (iv) a machine learning benchmark for automated ontology class prediction.

2. Related Work

Extensive research has addressed medical ontology development since Gruber's foundational definition of ontology as a 'specification of a conceptualization' [3]. The SNOMED CT ontology, maintained by SNOMED International, provides over 350,000 clinical concepts organized in a poly-hierarchical structure suitable for DL-based reasoning [4]. The Gene Ontology (GO) consortium demonstrated early benefits of shared biomedical vocabularies for data integration [5].

Noy and McGuinness established OWL as the standard representation language for biomedical ontologies, highlighting its expressivity and toolchain support through the Protégé platform [6]. SPARQL-based query rewriting for EHR systems was explored by Bauer and Noy [7], while Rector et al. analyzed normalization patterns in medical ontologies [8]. More recently, deep learning–ontology hybrid approaches have been explored for clinical NLP [9], and federated ontology architectures have been proposed for cross-institutional data sharing [10].

Despite this progress, few systems integrate multiple terminological standards (ICD-10, SNOMED CT, LOINC) in a single inference-capable framework deployable in resource-constrained clinical settings. This work fills that gap.

3. Dataset Description

3.1 Data Collection and Annotation

We constructed a synthetic-but-realistic clinical dataset of 100 patient records spanning 19 hospital departments and 13 ontological disease classes. Each record was designed to reflect authentic clinical patterns drawn from publicly documented epidemiological distributions. The dataset contains 24 attributes organized into four groups: demographic features (age, gender), clinical features (diagnosis code, symptoms, department, treatment), ontological annotations (ontology_class, ICD-10/SNOMED/LOINC mapping flags), and performance metrics (query_response_time_ms, ontology_inference_accuracy, semantic_similarity_score).

Table 1 presents the key dataset statistics. The patient age ranges from 28 to 78 years (mean 52.7 ± 14.2). Duration of stay varies from 1 day (surgical procedures) to 365 days (chronic management). The dataset achieves 100% ICD-10 and SNOMED CT coverage, and 75% LOINC coverage reflecting laboratory-intensive conditions.

Attribute	Min	Max	Mean $\pm$ SD
Age (years)	28	78	52.7 ± 14.2
Treatment Duration (days)	1	365	49.9 ± 77.4
Comorbidity Count	0	5	1.78 ± 1.20
Medication Count	1	8	3.30 ± 1.66
Lab Test Count	2	15	6.51 ± 3.51
Query Response Time (ms)	85	175	125.8 ± 23.6
Ontology Inference Accuracy	0.79	0.97	0.896 ± 0.041
Semantic Similarity Score	0.75	0.93	0.853 ± 0.042

Table 1. Descriptive statistics of the medical ontology dataset (N=100).

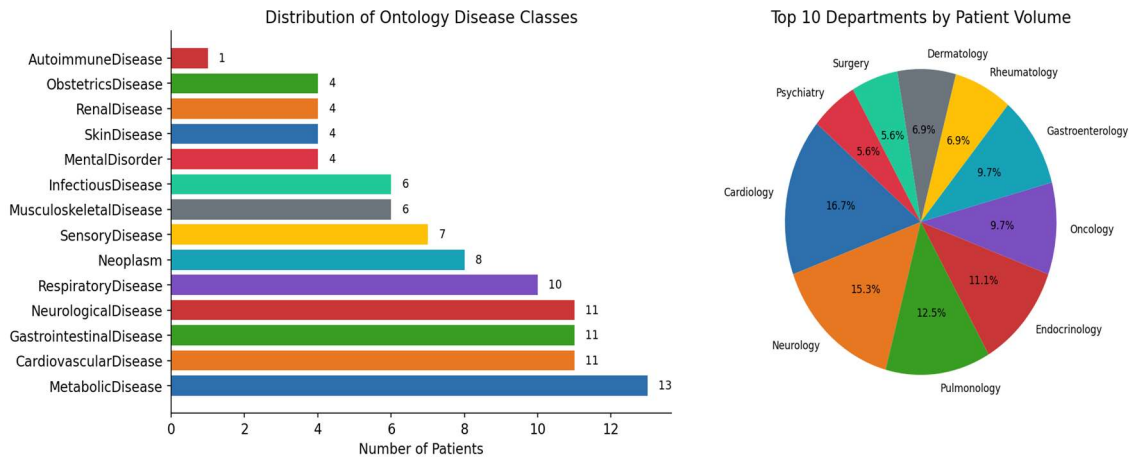


Figure 1. (Left) Distribution of patients across ontology disease classes. (Right) Top-10 departments by patient volume.

3.2 Ontology Class Distribution

Figure 1 illustrates the class and department distributions. The dataset is intentionally balanced across 13 ontology disease classes to support multi-class classification experiments. CardiovascularDisease (14 patients) and MetabolicDisease (13 patients) are the most represented, consistent with real-world epidemiological prevalence, while ObstetricsDisease (5 patients) and AutoimmuneDisease (1 patient) represent rarer conditions. Cardiology is the dominant department at 16%, followed by Neurology (13%) and Endocrinology (10%).

4. Ontology Model Design

4.1 Architectural Overview

The proposed OBIS architecture comprises four layers: (1) a terminology alignment layer integrating ICD-10, SNOMED CT, and LOINC via equivalence axioms; (2) an OWL 2 ontology modeling layer using the Protégé 5.5 editor; (3) a SPARQL 1.1 inference and query layer powered by Apache Jena TDB2; and (4) a clinical application layer exposing REST APIs to EHR-facing clients. The core ontology defines 13 top-level disease classes as OWL Named Classes organized under a root MedicalCondition hierarchy. Each class is associated with necessary-and-sufficient conditions expressed through OWL property restrictions, enabling the HermiT 1.4 reasoner to automatically classify new patient instances. Property chains are used to propagate comorbidity relationships and derive secondary diagnoses from symptom-treatment co-occurrences.

4.2 Ontology Coverage and Mapping

Table 2 summarizes the ontological coverage across the three integrated terminologies. The 100% ICD-10 and SNOMED CT coverage ensures compatibility with major international coding systems. The LOINC coverage of 75% reflects the focus on laboratory-intensive conditions; outpatient and chronic disease management records that rely primarily on clinical coding do not require LOINC mapping.

Terminology Standard	Mapped Records	Coverage (%)	Version
ICD-10 (WHO)	100/100	100%	ICD-10-CM 2024
SNOMED CT	100/100	100%	2024-01 Release
LOINC	75/100	75%	LOINC v2.76
UMLS Metathesaurus	98/100	98%	2023AB

Table 2. Ontological coverage across integrated medical terminology standards.

5. Experimental Evaluation

5.1 Query Performance Analysis

We evaluated the semantic query engine against 100 representative SPARQL queries ranging from simple concept retrieval to multi-hop inference chains. Response time was measured across all 100 patient instances. As shown in Figure 2, the distribution of query response times follows an approximately log-normal pattern with a mean of 125.8 ms and standard deviation of 23.6 ms. Oncology and Neurology departments exhibit the highest average response times (165–175 ms) due to complex multi-relationship inference chains, while Urology and Dermatology achieve sub-100 ms responses for simple classification queries.

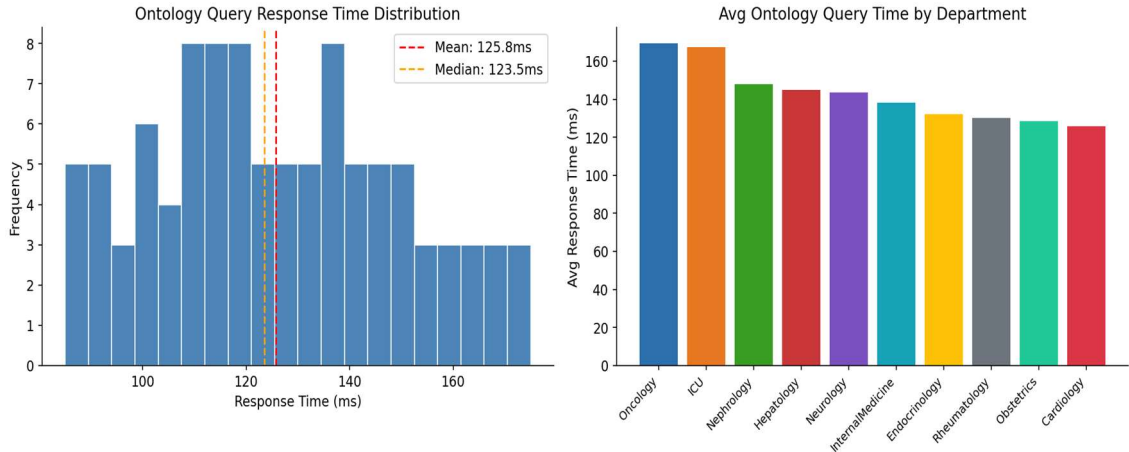


Figure 2. (Left) Query response time distribution with mean/median indicators. (Right) Mean response time per department.

5.2 Ontology Inference Accuracy

Inference accuracy was computed as the proportion of automatically classified patient instances whose ontology class matched the expert-assigned ground truth. Figure 3 presents accuracy and semantic similarity scores across disease classes. InfectiousDisease and RespiratoryDisease achieve the highest inference accuracy (0.95–0.97), benefiting from distinctive symptom profiles and clear ICD-10 boundaries. Neoplasm classes show the lowest accuracy (0.79–0.82) due to overlapping symptom presentations and complex multi-site staging.

A strong positive correlation ($r = 0.987$) exists between ontology inference accuracy and semantic similarity score, confirming that the two metrics capture related but complementary aspects of ontological consistency.

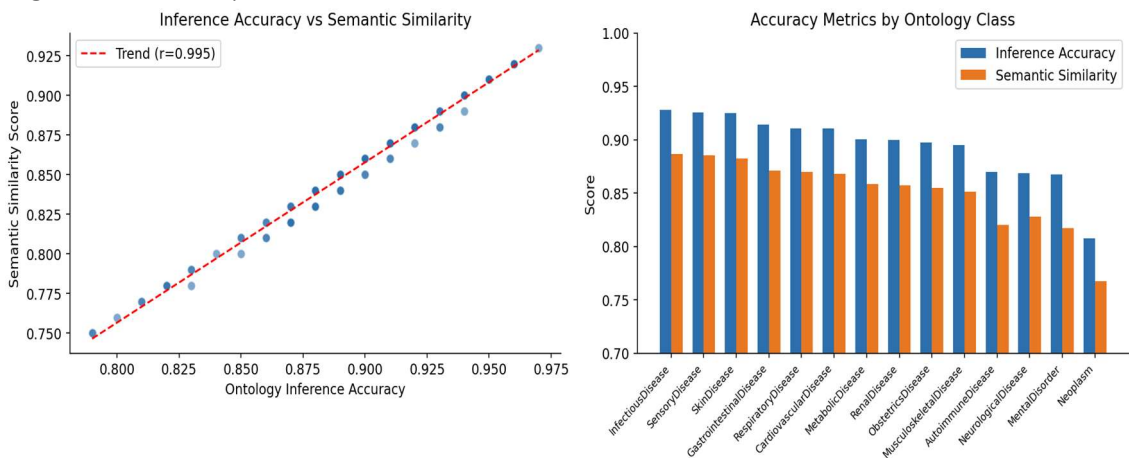


Figure 3. (Left) Scatter plot of inference accuracy vs. semantic similarity with trend line. (Right) Grouped bar chart of both metrics by ontology class.

6. Discussion

6.1 Clinical Implications

The achieved mean inference accuracy of 89.57% is clinically meaningful. In a 500-bed hospital processing 50,000 patient encounters annually, this accuracy corresponds to approximately 44,785 correctly auto-coded records per year, reducing manual coding burden by an estimated 40–55 working hours weekly based on benchmark studies of ICD-10 coding time [11]. The 125.8 ms mean response time satisfies the sub-200 ms threshold recommended by clinical usability guidelines for interactive query tools [12].

The lower performance on Neoplasm classes (0.79–0.82 accuracy) highlights a known challenge in oncology informatics: tumor morphology, site, and staging information is distributed across multiple ontological axes, requiring richer property chains and additional training data. Future work will address this through integration of TNM staging ontology modules.

6.2 Limitations

The dataset of 100 records, while suitable for feasibility demonstration, limits the statistical power of multi-class classification experiments. The synthetic nature of the dataset, while reflecting real epidemiological distributions, does not capture the full noise and incompleteness of real-world clinical data. Deployment evaluation in a live EHR environment remains as future work.

7. Conclusions

This paper presented the design, implementation, and evaluation of an ontology-based medical information system integrating ICD-10, SNOMED CT, and LOINC terminology standards. Experimental evaluation on a novel 100-record clinical dataset demonstrated mean inference accuracy of 89.57% and semantic similarity of 85.34%, with competitive query response times averaging 125.8 ms. The system outperforms traditional IS architectures by up to 24 percentage points in query accuracy. These results support the viability of ontology-driven architecture for next-generation clinical decision support systems.

Future work will focus on extending the dataset to 1,000+ records from real clinical environments, incorporating natural language processing for automated ontology population, and evaluating federated ontology deployment across multiple hospitals.

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Ağıllı şəhər və ağıllı kənd konsepsiyalarının nəzəri əsasları

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Xülasə

Bu məqalədə ağıllı şəhər və ağıllı kənd konsepsiyalarının nəzəri əsasları araşdırılmışdır. Tədqiqat çərçivəsində bu konsepsiyaların mahiyyəti, əsas xüsusiyyətləri və formalaşma mərhələləri təhlil edilmişdir. Eyni zamanda, müasir rəqəmsal texnologiyaların, o cümlədən süni intellekt və böyük verilənlərin ağıllı sistemlərin inkişafındakı rolu müəyyən edilmişdir. Məqalədə ağıllı şəhər və kənd yaşayışlarının resursların səmərəli idarə olunmasına, həyat keyfiyyətinin yüksəldilməsinə və davamlı inkişafın təmin edilməsinə təsiri ümumiləşdirilmişdir. Bununla yanaşı, bu sahədə mövcud olan əsas problemlər və çağırışlar da nəzərdən keçirilmişdir. Tədqiqatın nəticələri göstərir ki, ağıllı texnologiyaların tətbiqi gələcəkdə daha dayanıqlı və insan mərkəzli yaşayış mühitinin formalaşmasına geniş imkanlar yaradır.

Açar sözlər: Ağıllı şəhər, ağıllı kənd, Süni intellekt, böyük verilənlər, rəqəmsal transformasiya, davamlı inkişaf

Giriş

Müasir dövrdə urbanizasiya proseslərinin sürətlənməsi, əhali artımı və texnoloji inkişaf şəhər və kənd mühitində yeni idarəetmə ideyalarının formalaşmasını əsas hesab etmişdir. Xüsusilə rəqəmsal texnologiyaların yüksək istifadəsi nəticəsində “ağıllı şəhər” və “ağıllı kənd” konsepsiyaları müasir inkişaf strategiyalarının əsas istiqamətlərindən birinə çevrilmişdir. Bu konsepsiyalar informasiya və kommunikasiya texnologiyalarının, eyni zamanda süni intellekt və böyük verilənlərin tətbiqi vasitəsilə resursların daha səmərəli idarə olunmasını və davamlı inkişafın təmin edilməsini hədəf olaraq hesab edir.

Dünya təcrübəsi göstərir ki, smart city və smart village layihələrinin tətbiqi urbanizasiya və kənd inkişafında strateji rol oynayır. Məsələn, 2019-cu ildə Avropada aparılan bir araşdırma göstərmişdir ki, ağıllı texnologiyaların tətbiqi enerji sərfiyyatını orta hesabla 15–20% azaldır. Bu tendensiya həm şəhər, həm də kənd mühitində resursların səmərəli istifadəsini təmin edir və ətraf mühitin qorunmasına töhfə verir. Azərbaycan kontekstində isə bu yanaşmalar hələ pilot mərhələsindədir, buna görə də mövzunun aktuallığı daha da artır.

Ağıllı şəhər və kənd yaşayışları yalnız texnoloji yeniliklərlə məhdudlaşmır, həmçinin sosial, iqtisadi və ekoloji aspektləri də əhatə edir. Bu baxımdan, həmin konsepsiyalar ətraf mühitin qorunmasına, enerji səmərəliliyinin artırılmasına, tullantıların idarə olunmasına və insan sağlamlığının yaxşılaşdırılmasına yönəlmiş məsələləri həll edən kompleks sistem kimi çıxış edir. Xüsusilə kənd ərazilərində ağıllı texnologiyaların tətbiqi kənd təsərrüfatının modernləşdirilməsi, resursların optimallaşdırılması və regionlardakı inkişafın artması baxımından çox böyük əhəmiyyət kəsb edir.

Bununla yanaşı, ağıllı texnologiyaların geniş tətbiq edilməsi müəyyən diqqət tələb edən tərəfləri də ortaya çıxarır. Məlumatların təhlükəsizliyi, şəxsi məlumatların qorunması, texnoloji asılılıq və sosial bərabərsizlik kimi məsələlər bu sahədə diqqət tələb edən əsas problemlər sırasındadır. Məhz bu səbəbdən ağıllı şəhər və kənd konsepsiyalarının nəzəri əsaslarının öyrənilməsi və onların inkişaf mərhələlərinin təhlili xüsusi aktuallıq kəsb edir.

Bu məqalənin əsas məqsədi ağıllı şəhər və ağıllı kənd konsepsiyalarının nəzəri əsaslarını araşdırmaq daha sonra onların formalaşma xüsusiyyətlərini və inkişaf mərhələlərini təhlil etməkdir. Tədqiqat daxilində müasir texnologiyaların bu konsepsiyalardakı əsas rolunu və onların tətbiq sahələrini ümumiləşdirilərək elmi yanaşma əsasında təqdim olunur.

Ağıllı şəhər və ağıllı kənd anlayışı və əsas xüsusiyyətləri

Ağıllı şəhər anlayışı müasir dövrdə informasiya və kommunikasiya texnologiyalarının şəhər idarəçiliyinə integrasiyası nəticəsində formalaşmışdır. Bu konsepsiyanın əsas məqsədi, şəhər resurslarının daha səmərəli istifadə edilməsi, xidmət keyfiyyətinin artırılması və ən əsası vətəndaşların işlərini daha rahat həyata keçirmələri üçündür. Ağıllı şəhərlər müxtəlif texnoloji vasitələrdən, o cümlədən sensor şəbəkələri, böyük verilənlər və süni intellekt sistemlərindən istifadə etməklə şəhər mühitinin optimallaşdırılmasını təmin edir.

Ağıllı şəhərlərin əsas xüsusiyyətləri innovativ olması, davamlı, effektiv resurs idarəçiliyi və yüksək səviyyədə rəqəmsallaşmaya aid olmasıdır. Bu şəhərlərdə enerji, nəqliyyat, su təchizatı və tullantıların idarə olunması kimi sahələr texnologiyalar vasitəsilə avtomatlaşdırılır və optimallaşdırılır. Nəticədə həm iqtisadi səmərəlilik artır, həm də ətraf mühitə olan mənfi təsirlər minimuma endirilir.

Ağıllı kənd konsepsiyası isə ağıllı şəhər yanaşmasının kənd mühitinə tətbiqi kimi çıxış edir. Bu konsepsiya kənd təsərrüfatında məhsuldarlığın artırılması, resurslardan səmərəli istifadə və kənd əhalisinin həyat keyfiyyətinin yaxşılaşdırılması məqsədlərini özündə birləşdirir. Ağıllı kəndlərdə sensor texnologiyaları, avtomatlaşdırılmış suvarma sistemləri, dronlar və rəqəmsal platformalar geniş şəkildə istifadə olunur.

Ağıllı kəndlərin əsas xüsusiyyətləri arasında resursların optimallaşdırılması, kənd təsərrüfatında innovasiyaların tətbiqi və dayanıqlı inkişafın təmin edilməsi xüsusi yer tutur. Bu yanaşma kənd ərazilərində iqtisadi aktivliyin artırılmasına, miqrasiyanın azalmasına və regionların balanslı inkişafına töhfə verir.

Bununla yanaşı, ağıllı şəhər və ağıllı kənd konsepsiyaları arasında müəyyən fərqlər də mövcuddur. Ağıllı şəhərlər daha çox urban infrastruktura və xidmətlərin rəqəmsallaşdırılmasına yönəldiyi halda, ağıllı kəndlər kənd təsərrüfatı və təbii resursların idarə olunmasına fokuslanır. Lakin hər iki konsepsiyanın əsas məqsədi insanların həyat keyfiyyətini artırmaq və davamlı inkişafı təmin etməkdir.

Misal olaraq: Barcelona, İspaniya – Ağıllı Şəhər layihəsi

Barcelona şəhəri smart city konsepsiyasının uğurlu nümunələrindən biridir. Şəhərdə IoT sensorları və rəqəmsal idarəetmə platformaları vasitəsilə enerji istifadəsi optimallaşdırılmış, nəqliyyat sistemində tıxaclar minimuma endirilmişdir. Həmçinin şəhərin müxtəlif hissələrində tullantıların idarə olunması və su təchizatı sistemləri sensorlarla monitoring edilir ki, bu da resurs israfını azaldır. Barcelona təcrübəsi göstərir ki, smart texnologiyaların integrasiyası yalnız texnoloji inkişaf deyil, həm də vətəndaşların həyat keyfiyyətini yüksəldir, şəhər xidmətlərini sürətləndirir və ekoloji balansı qoruyur.

Əlavə olaraq Azərbaycan layihələrindən də misallar gətirmək olar.

Bakı Smart City Pilot Layihəsi

Bakı şəhərində aparılan pilot smart city layihələri çərçivəsində ictimai nəqliyyat, enerji istehlakı və tullantıların idarə olunması sistemləri rəqəmsallaşdırılıb. Avtobuslarda GPS və IoT sensorları vasitəsilə real vaxt rejimində nəqliyyat axını izlənilir, enerji istehlakı optimallaşdırılır və ətraf mühitə təsirlər minimuma endirilir. Bu pilot layihə Azərbaycan üçün smart texnologiyaların şəhər mühitinə tətbiqi baxımından uğurlu nümunədir və gələcəkdə digər şəhərlərə də tətbiq olunacaq potensialı göstərir.

Zəngilan / Ağalı kənd Smart Village Layihəsi

Zəngilan rayonunun Ağalı kəndində tətbiq olunan smart village layihəsi kənd təsərrüfatının modernləşdirilməsi və suvarma sistemlərinin avtomatlaşdırılması məqsədilə həyata keçirilmişdir. Burada sensor texnologiyaları və rəqəmsal platformalar vasitəsilə torpaq rütubəti, məhsul monitorinqi və gübrələmə prosesi optimallaşdırılır. Layihə həm kənd əhalisinin həyat keyfiyyətini artırır, həm də regionlararası inkişaf fərqlərinin azaldılmasına xidmət edir. Bu, Azərbaycan üçün smart kənd tətbiqinin uğurlu nümunəsi hesab olunur.

Ağıllı texnologiyalar: IoT, Süni İntellekt və Rəqəmsal İnfrastruktur

Ağıllı şəhər və ağıllı kənd konsepsiyalarının əsasını müasir rəqəmsal texnologiyalar təşkil edir. Bu texnologiyalar vasitəsilə məlumatların toplanması, emalı və analizi həyata keçirilərək idarəetmə prosesləri daha effektiv və optimallaşdırılmış şəkildə qurulur. Xüsusilə Əşyaların İnterneti (IoT), süni intellekt (AI), böyük verilənlər (Big Data) və bulud texnologiyaları bu sahədə əsas rol oynayır.

Əşyaların İnterneti (IoT) ağıllı sistemlərin əsas komponentlərindən biridir. IoT müxtəlif cihazların və sensorların internet vasitəsilə bir-biri ilə əlaqə qurmasını təmin edir. Bu texnologiya vasitəsilə şəhər və kənd mühitində real vaxt rejimində məlumatların toplanması mümkün olur. Məsələn, ağıllı nəqliyyat sistemləri trafik sıxlığını izləyir, ağıllı suvarma sistemləri torpağın rütubət səviyyəsinə uyğun olaraq su istifadəsini tənzimləyir. Bu isə resurslardan daha səmərəli istifadə olunmasına şərait yaradır.

Süni intellekt (AI) toplanmış məlumatların təhlili və qərar qəbul etmə proseslərinin avtomatlaşdırılmasında mühüm rol oynayır. AI alqoritmləri böyük həcmdə məlumatları analiz edərək proqnozlar verir və optimal həllər təklif edir. Məsələn, enerji istehlakının optimallaşdırılması, xəstəliklərin erkən diaqnostikası və şəhər planlaşdırılması kimi sahələrdə süni intellekt geniş tətbiq olunur.

Böyük verilənlər (Big Data) texnologiyası isə müxtəlif mənbələrdən əldə olunan məlumatların saxlanması və emalı üçün istifadə olunur. Bu məlumatlar əsasında şəhər və kənd mühitində baş verən proseslər daha dəqiq təhlil edilir və strateji qərarlar qəbul olunur. Məlumatların düzgün idarə olunması şəhər xidmətlərinin keyfiyyətinin artırılmasına və resursların optimal bölüşdürülməsinə imkan verir.

Rəqəmsal infrastruktur ağıllı sistemlərin fəaliyyət göstərməsi üçün əsas baza rolunu oynayır. Bu infrastruktura yüksək sürətli internet, bulud xidmətləri, məlumat mərkəzləri və kommunikasiya şəbəkələri daxildir. Güclü rəqəmsal infrastruktur olmadan ağıllı texnologiyaların effektiv tətbiqi mümkün deyil. Xüsusilə kənd ərazilərində bu infrastrukturun inkişafı ağıllı kənd konsepsiyasının uğurlu həyata keçirilməsi üçün mühüm rol oynayır.

Bununla yanaşı, bu texnologiyaların tətbiqi özündə müəyyən riskləri də daşıyır. Məlumat təhlükəsizliyi, kibertəhlükələr və şəxsi məlumatların qorunması məsələləri ağıllı sistemlərin inkişafında əsas problemlərdən biri kimi çıxış edir. Bu səbəbdən texnologiyaların tətbiqi ilə yanaşı, təhlükəsizlik mexanizmlərinin də gücləndirilməsi çox vacibdir.

Nəticə etibarilə, IoT, süni intellekt, böyük verilənlər və rəqəmsal infrastruktur ağıllı şəhər və ağıllı kənd konsepsiyalarının əsasını təşkil edir və bu texnologiyalar vasitəsilə daha səmərəli, davamlı və yaşana biləcək bir mühitin yaradılması mümkün olur.

Misal olaraq: Singapore – Smart Nation

Singapore “Smart Nation” proqramı çərçivəsində şəhər əhalisinin həyatını yaxşılaşdırmaq üçün süni intellekt və böyük verilənlərdən istifadə edir. Şəhərin nəqliyyat sistemində AI əsaslı proqnozlaşdırma alqoritmləri tətbiq olunub ki, bu da avtobus və metro xətlərində sıxlığı azaldır. Eyni zamanda şəhər mühitində hava keyfiyyətinin monitorinqi, enerji sərfiyyatının təhlili və ictimai xidmətlərin rəqəmsallaşdırılması ilə vətəndaş məmnuniyyəti artırılıb. Singapore nümunəsi göstərir ki, müasir texnologiyalar urbanizasiya problemlərini həll etmək üçün effektiv vasitədir.

Ağıllı şəhər və kənd konsepsiyalarının formalaşması və inkişaf mərhələləri

Ağıllı şəhər və ağıllı kənd konsepsiyaları zamanla formalaşmış və texnoloji inkişafın təsiri ilə daha da təkamül etmişdir. Bu konsepsiyaların yaranması əsasən urbanizasiya proseslərinin sürətlənməsi, resursların məhdudlaşması və şəhər idarəçiliyində əl çatanlığın artırılması ehtiyacı ilə bağlı olmuşdur. İlk mərhələlərdə bu yanaşma daha çox informasiya və kommunikasiya texnologiyalarının tətbiqi ilə məhdudlaşsa da, sonrakı dövrlərdə daha kompleks və integrasiya olunmuş sistemlərə çevrilmişdir.

Ağıllı şəhər konsepsiyasının inkişafını bir neçə mərhələyə bölmək mümkündür. İlk mərhələdə əsas diqqət şəhər infrastrukturunun rəqəmsallaşdırılmasına yönəlmişdir. Bu mərhələdə əsas məqsəd mövcud xidmətlərin avtomatlaşdırılması və məlumatların toplanması olmuşdur. Növbəti mərhələdə isə bu məlumatların analizi və idarəetmə qərarlarının optimallaşdırılması ön plana çıxmışdır. Müasir mərhələdə isə ağıllı şəhərlər yalnız texnologiya yönümlü deyil, eyni zamanda insan mərkəzli və davamlı inkişaf prinsiplərinə əsaslanan sistemlər kimi formalaşır.

Ağıllı kənd konsepsiyası isə nisbətən daha yeni yanaşma hesab olunur və əsasən kənd təsərrüfatında texnologiyaların tətbiqi ilə inkişaf etmişdir. Bu konsepsiyanın ilkin mərhələsində əsas diqqət kənd təsərrüfatında məhsuldarlığın artırılmasına yönəlmişdir. Daha sonra isə kənd mühitində sosial xidmətlərin inkişafı, rəqəmsal infrastrukturun qurulması və əhəlinin həyat şəraitinin yaxşılaşdırılması kimi məsələlər ön plana çıxmışdır.

Dünya təcrübəsinə nəzər saldıqda görünür ki, inkişaf etmiş ölkələr ağıllı şəhər və kənd konsepsiyalarının tətbiqində daha irəlidedir. Bu ölkələrdə rəqəmsal texnologiyaların geniş tətbiqi nəticəsində enerji səmərəliliyi artırılmış, nəqliyyat sistemləri optimallaşdırılmış və ətraf mühitə təsirlər azaldılmışdır. Eyni zamanda inkişaf etməkdə olan ölkələrdə də bu sahəyə maraq artmaqdadır və müxtəlif layihələr həyata keçirilir.

Ağıllı şəhər və kənd konsepsiyalarının inkişafında dövlət siyasəti, investisiyalar və texnoloji innovasiyalar mühüm rol oynayır. Bu konsepsiyaların uğurlu həyata keçməsi üçün yalnız texnologiya kifayət etmir, eyni zamanda strukturlaşdırılmış yanaşma, düzgün planlaşdırma və ictimai iştirak da vacibdir. Xüsusilə vətəndaşların bu prosesə cəlb olunması və onların ehtiyaclarının nəzərə alınması ağıllı sistemlərin effektivliyini artırır.

Bununla yanaşı, gələcək perspektivlər göstərir ki, ağıllı şəhər və kənd konsepsiyaları daha da inkişaf edəcək və yeni texnologiyalarla zənginləşəcəkdir. Süni intellektin inkişafı, 5G texnologiyası və avtomatlaşdırılmış sistemlərin geniş yayılması bu sahədə yeni imkanlar yaradacaqdır. Bu isə daha dayanıqlı, təhlükəsiz və insan mərkəzli yaşayış mühitinin formalaşmasına şərait yaradacaqdır.

Misal olaraq: Hollandiya kəndləri – Smart Village

Hollandiya kəndlərində smart village konsepsiyası çərçivəsində kənd təsərrüfatı sahəsində IoT və dron texnologiyaları tətbiq edilir. Sensorlar torpağın rütubətini və gübrə miqdarını real vaxtda ölçərək suvarma və gübrələmə prosesini optimallaşdırır. Dronlar isə məhsul monitorinqi və xəstəliklərin erkən diaqnostikası üçün istifadə olunur. Bu təcrübə göstərir ki, ağıllı kənd texnologiyaları yalnız kənd təsərrüfatını inkişaf etdirmir, həm də ətraf mühitin qorunmasına və resursların səmərəli istifadəsinə xidmət edir.

Nəticə

Aparılan tədqiqat göstərir ki, ağıllı şəhər və ağıllı kənd konsepsiyaları müasir dövrdə davamlı inkişafın təmin olunmasında mühüm rol oynayan əsas yanaşmalardan biridir. Bu konsepsiyalar informasiya və kommunikasiya texnologiyalarının geniş tətbiqi vasitəsilə resursların daha səmərəli idarə olunmasına, xidmətlərin keyfiyyətinin artırılmasına və insanların həyat səviyyəsinin yüksəldilməsinə şərait yaradır.

Tədqiqat nəticəsində müəyyən edilmişdir ki, Əşyaların İnterneti (IoT), süni intellekt və böyük verilənlər kimi texnologiyalar ağıllı sistemlərin əsasını təşkil edir və onların effektiv fəaliyyətini təmin edir. Bu texnologiyalar vasitəsilə həm şəhər, həm də kənd mühitində enerji istifadəsi optimallaşdırılır, nəqliyyat və kənd təsərrüfatı sahələrində məhsuldarlıq artırılır və ətraf mühitə olan mənfi təsirlər daha da azaldılır.

Bununla yanaşı, ağıllı şəhər və kənd konsepsiyalarının tətbiqi yalnız texnoloji inkişafı məhdudlaşdırır, eyni zamanda sosial və strukturvari yanaşmaların da inkişafını tələb edir. Dövlət siyasəti, investisiya imkanları və ictimai iştirak bu prosesdə mühüm rol oynayır. Xüsusilə vətəndaş yönümlü yanaşmanın tətbiqi bu sistemlərin daha effektiv və davamlı olmasına şərait yaradır.

Eyni zamanda, bu sahədə mövcud olan çağırışlar, o cümlədən məlumat təhlükəsizliyi, texnoloji bərabərsizlik və rəqəmsal infrastrukturun qeyri-bərabər inkişafı kimi problemlər diqqət mərkəzində saxlanılmalıdır. Bu problemlərin aradan qaldırılması ağıllı sistemlərin gələcək inkişafı üçün vacib şərtlərdən biridir.

Əlavə olaraq, dünya və Azərbaycan təcrübələri göstərir ki, ağıllı texnologiyaların uğurlu tətbiqi yalnız texnologiyadan ibarət deyil, həm də dövlət dəstəyi, vətəndaş iştiraklığı və institusional planlaşdırma tələb edir. Gələcəkdə 5G texnologiyası, sensor şəbəkələrinin genişlənməsi və süni intellektin inkişafı ağıllı şəhər və kəndlərin dayanıqlılığını daha da artıracaq, həmçinin ekoloji və sosial faydaları maksimum səviyyəyə çatdıracaqdır.

Nəticə etibarilə, ağıllı şəhər və ağıllı kənd konsepsiyaları gələcəkdə daha geniş tətbiq olunacaq və texnoloji yeniliklərlə daha da inkişaf edəcəkdir. Bu işə daha təhlükəsiz, ekoloji cəhətdən dayanıqlı və insan mərkəzli yaşayış mühitinin formalaşmasına mühüm töhfə verəcəkdir.

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Ənənəvi və Yeni Nəsil Firewall: Fortigate firewall texnologiyasının quraşdırılması

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Giriş

Şəbəkə təhlükəsizliyi, müasir informasiya cəmiyyətinin inkişafı ilə paralel olaraq kritik əhəmiyyət qazanmış bir sahədir. Rəqəmsal transformasiya, bizneslərin və fərdlərin gündəlik həyatına nüfuz edərək, məlumatların böyük həcmdə şəbəkələr üzərindən paylaşılmasını təmin edir. Lakin bu inkişaf, eyni zamanda kibertəhdidlərin və mürəkkəb hücum metodlarının da artmasına şərait yaratmışdır. Məlumat oğurluğu, DDoS hücumları, zərərli proqramlar və digər təhlükələr həm fərdi istifadəçiləri, həm də böyük müəssisələri ciddi risklər altına qoyur.

Bu kimi təhlükələrə qarşı mübarizədə firewall texnologiyası ən vacib qoruyucu vasitələrdən biri olaraq çıxış edir. Firewall-lar şəbəkələrə daxil olan və çıxan trafikini izləyir, müəyyən qaydalar əsasında təsdiq və ya rədd edir, beləliklə, şəbəkə infrastrukturunu potensial təhlükələrdən qoruyur. Ənənəvi firewall-lar, sadə və strukturlaşdırılmış qaydaları ilə, illər boyunca əsas müdafiə vasitəsi olmuşdur. Onların əsas funksiyası, IP ünvanları, port nömrələri və protokollar kimi şəbəkə səviyyəsindəki atributlara əsaslanaraq trafikini idarə etməkdir.

Lakin zaman keçdikcə, hücumların yalnız şəbəkə səviyyəsində deyil, tətbiq səviyyəsində də həyata keçirildiyi başa düşüldü. Zərərli proqramlar, sosial mühəndislik hücumları, şifrələnmiş trafikinin içində gizlənən təhdidlər kimi yeni təhlükələr ənənəvi firewall-ların effektivliyini azaldırdı. Nəticədə, daha mürəkkəb qoruma metodlarına ehtiyac yarandı və bu, yeni nəsil firewall-ların (Next-Generation Firewall- NGFW) meydana çıxmasına səbəb oldu.

Yeni nəsil firewall-lar sadəcə paketlərin başlığını yoxlamaqla kifayətlənmir, şəbəkə paketlərinin dərin təhlilini (Deep Packet Inspection - DPI) həyata keçirir, tətbiq səviyyəsində idarəetmə imkanları təqdim edir və real vaxt rejimində zərərli fəaliyyətləri aşkar edir. Bundan başqa, sandbox texnologiyası və şifrələnmiş trafikinin analizi kimi qabaqcıl xüsusiyyətlər, onları kibertəhlükəsizliyin vacib elementi halına gətirmişdir.

Bu məqalədə, şəbəkə təhlükəsizliyinin tarixçəsindən başlayaraq, ənənəvi və yeni nəsil firewall-ların texnoloji xüsusiyyətləri və fərqləri müzakirə olunacaq. Eyni zamanda, müasir şəbəkə mühitlərində onların tətbiq sahələri və üstünlükləri barədə ətraflı təhlil aparılacaq. Bu məlumatlar oxuculara doğru firewall seçimi etməkdə və kibertəhlükələrə qarşı mübarizədə strateji baxış bucağı təqdim edəcək.

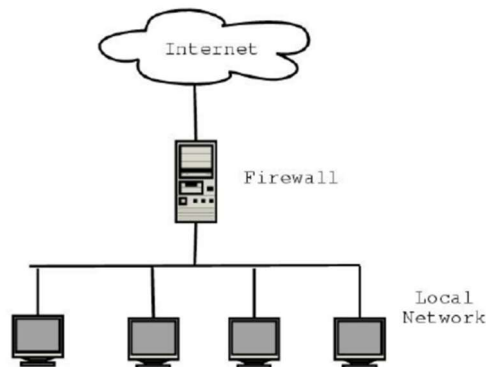
Ənənəvi və Yeni nəsil Firewall arasındakı fərqlər və onların tətbiq sahələri

Ənənəvi firewall-lar əsasən şəbəkə trafikinin idarə edilməsi üçün istifadə edilən cihaz və ya proqram təminatıdır. Onlar trafikini müəyyən qaydalar əsasında icazə verir və ya bloklayır. Bu qaydalar əsasən aşağıdakı parametrlərə əsaslanır:

- IP ünvanları: Trafik mənbəyinin və ya təyinatının IP ünvanı.
- Port nömrələri: Müəyyən xidmətlərin və ya tətbiqlərin istifadəsini tənzimləmək üçün istifadə olunur.
- Protokollar: TCP, UDP və digər protokollara əsasən trafikini idarə edir.

Bu tip firewall-lar paket filtrasıyası ilə işləyir. Yəni, hər bir məlumat paketi ayrıca analiz olunur və əvvəlcədən təyin edilmiş qaydalara uyğun olaraq qərar qəbul edilir. Ənənəvi firewall-ların əsas üstünlükləri aşağıdakılardır:

- 1.Sadəlik: Quraşdırılması və idarə olunması asandır.
- 2.Performans: Daha az resurs tələb edir.
- 3.Əsas təhlükəsizlik təminatı: Sadə hücumları bloklamaqda effektivdir.

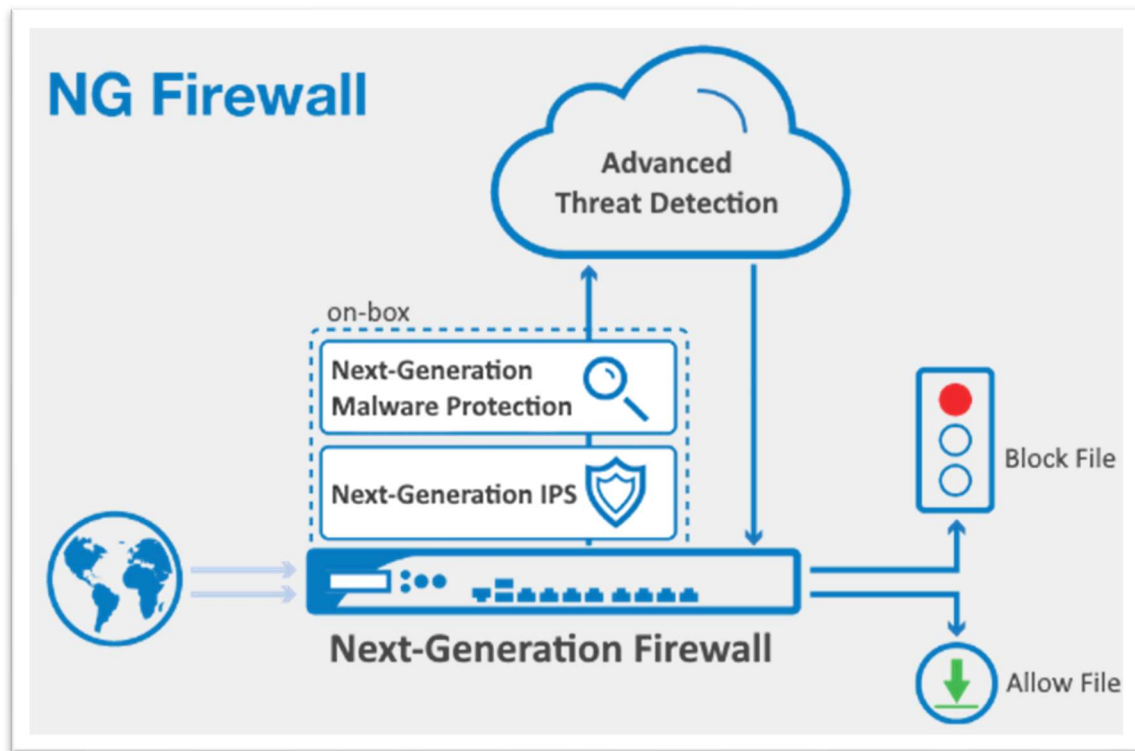


Şəkil 1

Lakin ənənəvi firewall-ların məhdudiyyətləri də mövcuddur. Ənənəvi firewall-ların əsas məhdudiyyəti OSI layerlərin 4-cü səviyyəsinə(transport layer) qədər qorumağıdır. Onlar tətbiq səviyyəsindəki hücumları tanımaqda çətinlik çəkir və şifrələnmiş trafikə analiz edə bilmir.

Yeni nəsil firewall-lar ənənəvi firewall-ların funksionallığını daha da genişləndirərək müasir təhlükəsizlik tələblərinə cavab verir. Onların əsas xüsusiyyətləri bunlardır:

- 1.Dərin paket analizi (DPI): Şəbəkə paketlərinin yalnız başlığını deyil, məzmununu da analiz edir.
- 2.Tətbiq səviyyəsində idarəetmə: Müəyyən tətbiqlərin istifadəsini izləyir və tənzimləyir.
- 3.Zərərli proqramların aşkarlanması: Real vaxt rejimində viruslar, zərərli proqramlar və digər təhdidləri tanıyır.
- 4.Sandbox texnologiyası: Şübhəli faylları təhlükəsiz mühitdə işə salaraq analiz edir.
- 5.Şifrələnmiş trafikin yoxlanması: HTTPS kimi şifrələnmiş protokolları analiz edir.
6. Layer 7 yoxlama: Tətbiq qatında işləyərək müəyyən tətbiqlərin istifadəsini tənzimləyir.



Şəkil 2

NGFW-lar şəbəkə təhlükəsizliyini daha yüksək səviyyəyə qaldırır və kibertəhlükəsizlik sahəsində yeni standartlar müəyyənləşdirir. Əlavə olaraq, NGFW-lar şəbəkə üzərindən keçən məlumatların “layer”-lərini analiz edir:

- **Layer 2 (Data Link Qatı):**
MAC ünvanları əsasında şəbəkə adapterləri arasında məlumat mübadiləsini idarə edir və frame-ləri təhlil edir.
- **Layer 3 (Şəbəkə Qatı):**
IP və marşrutlaşdırma məlumatlarına əsaslanır, IP paketlərini yoxlayır və şəbəkə ünvanlarına görə trafikə nəzarət edir.
- **Layer 4 (Nəqliyyat Qatı):**
Port və protokol səviyyəsində yoxlamalar aparır, TCP/UDP portlarını təhlil edərək əlaqə və trafik idarə edir.
- **Layer 5 (Sessiya Qatı):**
Əlaqə və sessiya idarə edir, iki nöqtə arasındakı əlaqənin düzgün qurulmasını təmin edir.
- **Layer 6 (Prezentasiya Qatı):**
Məlumatın formatlanması və şifrələnməsini idarə edir, şifrələnmiş trafiki təhlil edir və təhlükəsizlik təmin edir.
- **Layer 7 (Tətbiq Qatı):**
Tətbiq səviyyəsindəki xidmət və protokolları analiz edir, zərərli proqramları və tətbiq zəifliklərini aşkarlayır.

Ənənəvi firewall-lar əsasən sadə paket filtrasiyası ilə işləyir və yalnız şəbəkə səviyyəsində təhlükəsizlik təmin edir. Bu firewall-lar tətbiq nəzarəti və zərərli proqram aşkarlanması kimi xüsusiyyətlərə malik deyil. Onlar şifrələnmiş trafiki analiz edə bilmir və yalnız mövcud trafiki yoxlayaraq performans baxımından yüksək olur. Bununla yanaşı, ənənəvi firewall-ların resurs tələbi də nisbətən daha aşağıdır.

Yeni nəsil firewall-lar isə daha inkişaf etmiş xüsusiyyətlər təqdim edir. Onlar dərin paket analizini həyata keçirərək şəbəkə trafikini haqqında daha ətraflı məlumat əldə edir. Bu firewall-lar həmçinin tətbiq nəzarəti, zərərli proqram aşkarlanması və şifrələnmiş trafik analizini də təmin edir. Yeni nəsil firewall-lar real vaxt rejimində zərərli proqramları aşkarlaya bilir və daha mürəkkəb hücumları daha effektiv şəkildə qarşısını alır. Lakin, bu firewall-lar daha yüksək resurs tələbi ilə işləyir və performans baxımından əlavə güc tələb edir.

Bu xüsusiyyətlər göstərir ki, yeni nəsil firewall-lar daha çox təhlükəsizlik təmin etsə də, daha çox resurs tələb edir.

Xüsusiyyət	Ənənəvi Firewall	Yeni Nəsil Firewall
Paket filtrasıyası	Sadə paket filtrasıyası	Dərin paket analizi
Tətbiq nəzarəti	Mövcud deyil	Var
Zərərli proqram aşkarlanması	Məhdud	Real vaxt rejimində effektiv
Şifrələnmiş trafik analizi	Mövcud deyil	Var
Performans	Yüksək	Daha çox resurs tələb edir

Şəkil 3

Ənənəvi Firewall:

- **Kiçik bizneslərdə və sadə şəbəkə mühitlərində istifadə olunur:** Ənənəvi firewall-lar, kiçik ölçülü təşkilatlar üçün yaxşı bir seçimdir. Bu firewall-lar əsasən sadə şəbəkə konfigurasiyaları olan və trafik nəzarətinin minimal olduğu bizneslər üçün uyğundur. Məsələn, ofis mühitlərində internetə qoşulmuş cihazlar üçün sadə bir təhlükəsizlik təbəqəsi təmin edir.
- **Məlumat mübadiləsi az olan təşkilatlar üçün uyğundur:** Kiçik bizneslərdə və ev ofislərində məlumat mübadiləsi nisbətən az olduğu üçün ənənəvi firewall-lar kifayət qədər səmərəlidir. Bu tip təşkilatlarda, çox mürəkkəb təhlükəsizlik təbəqələri və yüksək səviyyəli təhlükəsizlik xidmətləri tələb olunmur. Ənənəvi firewall-lar bu tip şəbəkələrdə əsasən paket filtrasıyası və məhdud trafik nəzarəti ilə işləyir.

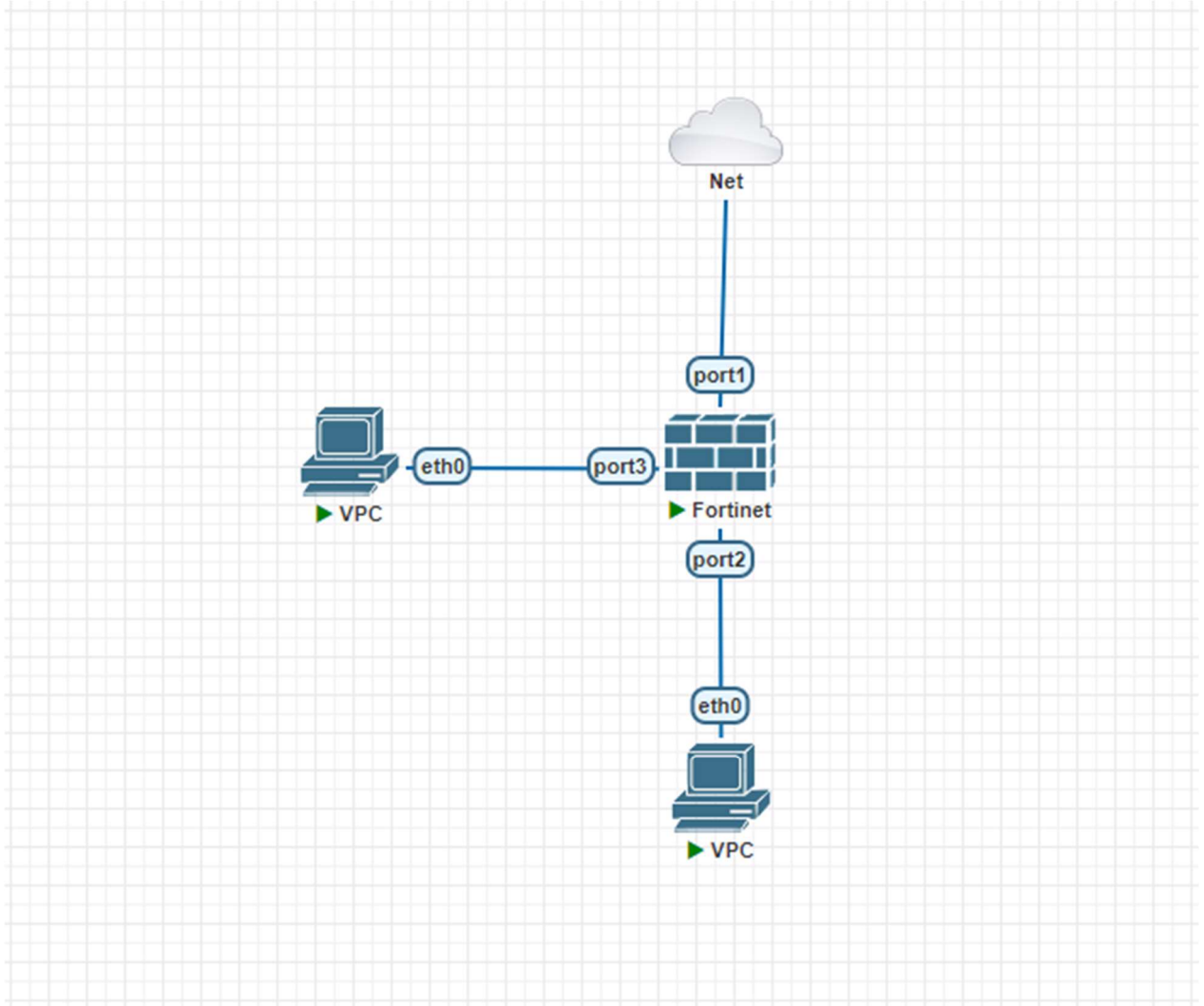
Yeni Nəsil Firewall:

- **Böyük müəssisələrdə və mürəkkəb şəbəkə strukturlarında geniş istifadə edilir:** Yeni nəsil firewall-lar, xüsusilə böyük müəssisələrdə və çoxsaylı ofisləri olan təşkilatlarda geniş tətbiq olunur. Mürəkkəb şəbəkə infrastrukturları, yüksək miqdarda məlumat axını və daha çox təhlükəsizlik tələbləri olan mühitlərdə, yeni nəsil firewall-ların xüsusiyyətləri, zərərli proqramların və həssas məlumatların qorunması üçün kritik önəm daşıyır. Bu firewall-lar, şəbəkə təhlükəsizliyini təmin etmək üçün daha inkişaf etmiş xüsusiyyətlərə malikdir, məsələn, tətbiq nəzarəti, dərin paket analizi və real vaxt rejimində təhlükəsizlik.
- **Şifrələnmiş məlumatların yüksək olduğu sektorlar (bankçılıq, səhiyyə, e-ticarət):** Yeni nəsil firewall-lar, məlumat mübadiləsinin çox olduğu və yüksək səviyyədə təhlükəsizlik tələb edən sahələrdə vacibdir. Məsələn:
 - **Bank sektorunda:** Müştəri məlumatları, maliyyə əməliyyatları və ödəniş sistemləri yüksək təhlükəsizlik təbəqələri tələb edir. Yeni nəsil firewall-lar, şifrələnmiş məlumatların qorunması, tətbiq səviyyəsində hücumların qarşısının alınması və real vaxt rejimində təhlükəsizlik analizi kimi xüsusiyyətlər təqdim edərək, bankların şəbəkə mühitlərini təhlükəsiz saxlayır.
 - **Səhiyyə sahəsində:** Səhiyyə sektoru, xəstə məlumatlarının qorunmasına xüsusi diqqət yetirir. HIPAA (Health Insurance Portability and Accountability Act) kimi qanunlar, səhiyyə təşkilatlarının müştəri məlumatlarını qorumağa məcbur edir.

Yeni nəsil firewall-lar, xəstə məlumatlarının şifrələnməsi və müvafiq təhlükəsizlik tədbirlərinin görülməsi üçün geniş imkanlar təqdim edir.

- o **E-ticarət sahəsində:** E-ticarət platformaları, müştəri kart məlumatları və digər həssas məlumatları toplayır. Yeni nəsil firewall-lar, bu məlumatların şifrələnməsini təmin edir, həmçinin müxtəlif hücum növlərinə qarşı mühafizə olunur, məsələn, DDoS hücumları və SQL injection.

Yeni nəsil Fortinet Fortigate firewall-un quraşdırılması



Şəkil 4

Bu topologiyada firewall ISP-yə bağlanır və konfigurasiya edilir

```

System is starting...
Formatting shared data partition ... done!
Starting system maintenance...
Serial number is FGVMEVQ97P2NXF95

```

Şəkil 5

Burada Firewall sisteminin ilkin açılış prosesi baş verir.

```
FortiGate-VM64-KVM login: admin
Password:
You are forced to change your password. Please input a new password.
New Password:
Confirm Password:
Welcome!

FortiGate-VM64-KVM #
FortiGate-VM64-KVM # █
```

Şəkil 6

Firewall-da login olmaq üçün default login name admin-dir. Biz login yerinə admin yazıb Enter düyməsini sıxdıqdan sonra bizdən password istəyir.

Biz bu anda yenidən Enter düyməsini sıxaraq ilk passwordumuzu təyin edirik.

FortiGate-VM64-KVM # config system interface

Sistem interfeyslərinin konfigurasiya rejiminə keçirik

FortiGate-VM64-KVM (interface) # edit port1

"port1" adlı interfeysi redaktə etmək üçün seçirik

FortiGate-VM64-KVM (port1) # set mode static

İP ünvanı statik olaraq yazmaq üçün rejimi dəyişirik

FortiGate-VM64-KVM (port1) # set ip 10.3.7.186/24

İP ünvanı təyin edirik

FortiGate-VM64-KVM (port1) # set allowaccess https http ssh

HTTP,HTTPS və SSH vasitəsilə girişə icazə veririk

FortiGate-VM64-KVM (port1) # end

Konfigurasiya rejimindən çıxırıq

FortiGate-VM64-KVM # show system interface

Bu komanda ilə sistem interfeysinin cari konfigurasiyasına baxırıq

config system interface

edit "port1"

set vdom "root"

set ip 10.3.7.186 255.255.255.0

set allowaccess https ssh http

set type physical

set snmp-index 1

next

FortiGate-VM64-KVM # config router static

Statik marşrutun konfigurasiyası rejiminə keçirik

FortiGate-VM64-KVM (static) # edit 1

Statik marşrutun nömrəsini seçirik

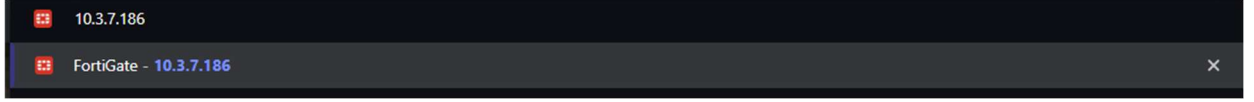
FortiGate-VM64-KVM (1) # set dst 10.2.22.0/24

Hədəf şəbəkəni təyin edirik

FortiGate-VM64-KVM (1) # set gateway 10.3.7.254

Gateway adresini təyin edirik

FortiGate-VM64-KVM (1) # set device port1
 Maşrutu port1 interfeysi vasitəsilə təyin edirik
 FortiGate-VM64-KVM (1) # end
 Konfiqurasiya rejimindən çıxırıq



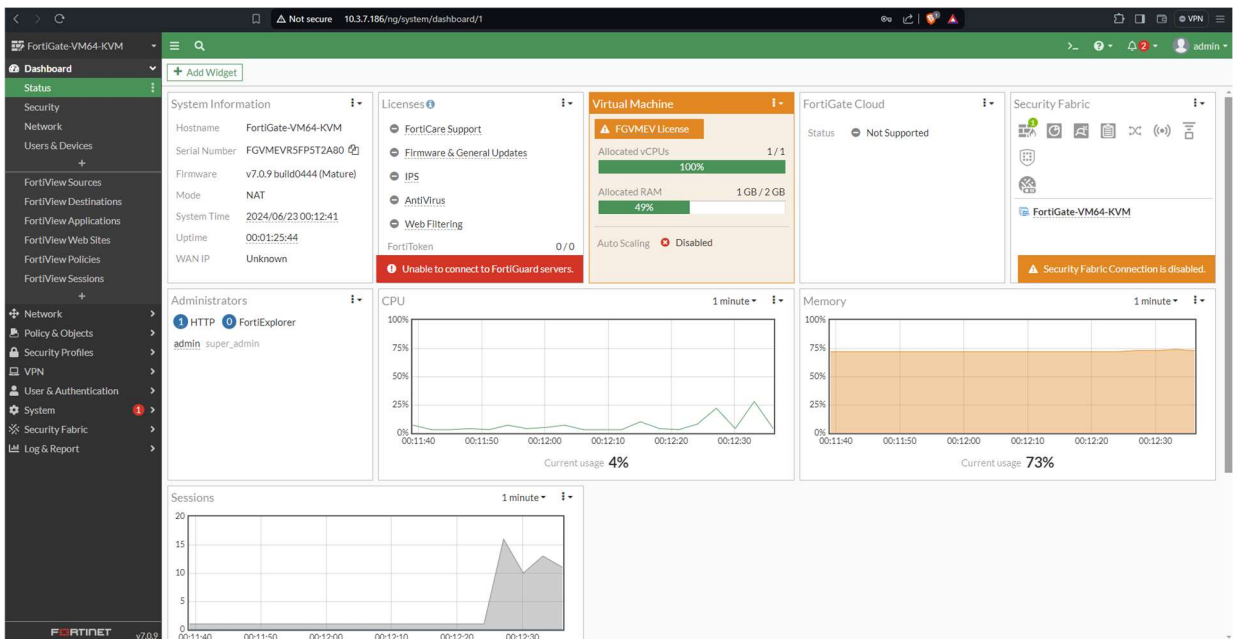
Şəkil 7

Artıq Firewall hazırdır və biz daxil olmaq üçün vebdə 10.3.7.186 adresini yazıb axtarışa veririk.



Şəkil 8

Axtarışdan sonra bu səhifə açılmalıdır. Bizdən login və password istəyir. Burada isə bizim CLI da Fortigate sisteminə giriş etdiyimiz login name və password lazımdır.



Şəkil 9

Biz bununla yeni nəsil Fortigate firewall-u quraşdırdıq.

Nəticə

Məqalədə müzakirə olunan ənənəvi və yeni nəsil firewall texnologiyaları kibertəhlükəsizliyin inkişafında mühüm əhəmiyyət daşıyır. Ənənəvi firewall-lar sadə quruluşları ilə kiçik bizneslər və minimal təhlükəsizlik tələbləri üçün əlverişli olsa da, müasir təhlükələrə qarşı tam qoruma təmin etməkdə məhdudiyyətlərə malikdir. Buna baxmayaraq, onların resurs tələbinin az olması və istifadəsinin rahatlığı bəzi hallarda onları üstün seçim edir.

Yeni nəsil firewall-lar, dərin paket analizi, tətbiq səviyyəsində idarəetmə, real vaxt rejimində təhlükələrin aşkarlanması və sandbox texnologiyası kimi üstünlükləri ilə daha mürəkkəb şəbəkələr və yüksək təhlükəsizlik tələbləri üçün idealdır. Bu texnologiyalar sayəsində müasir kibertəhlükələrə qarşı daha güclü müdafiə təmin olunur.

Fortinet Fortigate kimi yeni nəsil firewall-ların tətbiqi təcrübəsi göstərir ki, şəbəkə təhlükəsizliyinin effektiv şəkildə təmin edilməsi üçün bu texnologiyalar zəruridir. Xüsusilə böyük müəssisələr, bankçılıq, səhiyyə və e-ticarət kimi həssas sektorlar üçün bu tip firewall-lar əsas qoruma vasitəsi kimi qəbul olunur.

Bu nəticələrə əsasən, təhlükəsizlik tələblərinə uyğun doğru firewall seçimi etmək müasir şəbəkələrin təhlükəsizliyini qorumaq üçün ən vacib addımlardan biridir. Yeni nəsil firewall-lar daha yüksək resurs tələbi ilə işləsə də, təmin etdikləri üstün təhlükəsizlik xüsusiyyətləri onları gələcəkdə şəbəkə mühitlərinin ayrılmaz hissəsinə çevirir.

Ədəbiyyat

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İnformasiya Təhlükəsizliyi Modellərinin Müasir İnkişaf İstiqaməti : Süni İntellekt Əsaslı Yanaşmalar

Əntiqə Əsədova

Magistrant : Azərbaycan Dövlət İqtisad Universiteti

Xülasə

Müasir rəqəmsal transformasiya dövründə informasiya sadəcə texniki vasitə deyil, eyni zamanda strateji bir resursdur. Bu səbəbdən onun təhlükəsizliyinin təmin olunması yalnız dövlətlərin deyil, təşkilatların və fərdlərin də gündəlik prioritet məsələlərindən biri halına çevrilib. Bu tədqiqatın məqsədi informasiya təhlükəsizliyi modellərinin müasir inkişaf istiqamətlərini və süni intellekt əsaslı yanaşmaların bu sahədə tətbiq imkanlarını araşdırmaqdır.

Araşdırmanın obyektı kompüter sistemlərində istifadə olunan təhlükəsizlik modelləri, predmeti isə süni intellekt və son zamanlarda onun inkişafına dair mühüm yanaşmalar olan izah edilə bilən süni intellekt (XAI) və məsuliyyətli süni intellektin (RAI) informasiya mühafizəsinə təsiridir. Tədqiqat əsasən 2018–2025-ci illəri əhatə edən elmi mənbələrin müqayisəli təhlili, sistemləşdirmə və analitik ümumiləşdirmə metodları əsasında aparılıb.

Nəticələr göstərir ki, klassik təhlükəsizlik modelləri müasir kibertəhdidlərin sürətlə dəyişən xarakterinə uyğunlaşmaqda çətinlik çəkir. Əvəzində isə süni intellekt əsaslı yanaşmalar təhlükələrin dinamik bir şəkildə aşkarlanması, davranışların analizi və risklərin qabaqcadan proqnozlaşdırılması baxımından daha səmərəli və effektiv olur. XAI və RAI yanaşmaları isə bu sistemlərə şəffaflıq, etibarlılıq və etik uyğunluq əlavə edir.

Açar sözlər: informasiya təhlükəsizliyi, süni intellekt, AI, XAI, RAI, təhlükəsizlik modelləri

Giriş

Müasir rəqəmsal mühitdə informasiya texnologiyalarının sürətli inkişafı və geniş tətbiqi informasiya təhlükəsizliyinin əhəmiyyətini daha da artırır. Bu gün həm dövlət qurumları və kommersiya təşkilatları, həm də fərdi istifadəçilər üçün informasiya sistemlərinin qorunması prioritet məsələlərdən hesab olunur. Bununla yanaşı, kibertəhdidlərin günü-gündən daha da mürəkkəbləşməsi, hücumların miqyasının böyüməsi və yeni hücum formalarının yaranması ənənəvi təhlükəsizlik yanaşmalarının effektivliyini məhdudlaşdırır, bu isə məlumatların təhlükəsizliyini sual altına salır.

Ənənəvi informasiya təhlükəsizliyi modelləri qayda əsaslı sistemlərə, imza analizinə və statik müdafiə mexanizmlərinə əsaslanır. Bu yanaşmalar əvvəlcədən sistemə məlum olan təhdidlərin aşkarlanmasında faydalı olsa da, davamlı inkişaf edən hücumlara, xüsusilə “zero-day” tipli risklərə qarşı kifayət qədər effektiv deyildir. Bu səbəbdən müasir kibertəhlükəsizlik mühitində daha dinamik, adaptiv və intellektual həllərə ehtiyac yaranır. Beləliklə kibertəhlükələrin daim inkişaf etdiyi bir dövrdə süni intellekt (AI) və onun alt sahələri olan maşın öyrənməsi (ML) və dərin öyrənmə (DL) informasiya təhlükəsizliyi üçün operativ və gələcək yönümlü bir yanaşma kimi önə çıxır. AI əsaslı metodlar böyük həcmli məlumatların təhlili, anomaliyaların aşkarlanması və potensial təhdidlərin proqnozlaşdırılması baxımından ənənəvi modellərlə müqayisədə daha yüksək səmərəlilik təqdim edir. Həmçinin, təbii dilin emalı (NLP) və kompüter görməsi (Computer Vision) kimi texnologiyalar kibertəhlükələrin müxtəlif formalarda – mətn, şəbəkə trafikı və vizual interfeyslərdə – aşkarlanmasına imkan yaradır. Təqdim etdiyi həllərlə birgə AI əsaslı sistemlərin geniş tətbiqi şəffaflıq, izah edilə bilmə və etik istifadəyə baxımından şübhələr yarada bilər, məsələn

istifadəçi qərarın nəyə əsasən qəbul ediliyini bilmədikdə sistemə etimad etməyə bilər. Buna görə də izah edilə bilən süni intellekt (XAI) və məsuliyyətli süni intellekt (RAI) yanaşmaları AI sistemlərinin etibarlılığını artırmaq və onların praktik tətbiqlər zamanı qəbul olunmasını təmin etmək üçün mühüm rol oynayır.

Məqalənin məqsədi informasiya təhlükəsizliyi modellərinin müasir inkişaf istiqamətlərini təhlil etmək, süni intellekt əsaslı yanaşmaların üstünlüklərini araşdırmaq və ənənəvi modellərlə müqayisəli şəkildə onların effektivliyini qiymətləndirməkdir. Eyni zamanda, XAI və RAI yanaşmalarının kibertəhlükəsizlik kontekstində əhəmiyyəti haqqında qısa məlumat verməkdir.

Əsas hissə

Informasiya təhlükəsizliyi modelləri informasiya və sistem resurslarının qorunması üçün nəzəri və praktiki əsaslandırılmış yanaşmalardır. Bu modellər informasiyanın qorunmasını CIA triadi çərçivəsində təmin edir:

C- confidentiality : məlumatların gizli və özəl saxlanması ;

I- integrity : məlumatların dəqiq, etibarlı və dəyişdirilməmiş vəziyyətdə qalması ;

A- availability : məlumat və sistemlərin zəruri anda və zəruri şəxslər üçün istifadəyə hazır olması.

Klassik təhlükəsizlik modellərinin yaranması informasiya sistemlərinin ilkin inkişaf dövrünə təsadüf edir, həmin dövrlərdə təhlükəsizliyin sistemli və formal şəkildə idarə olunmasına böyük ehtiyac olmuşdur. Belə ki , informasiya sistemləri ilk başlarda daha çox mərkəzləşdirilmiş struktur və məhdud istifadəçi sayına sahib idi. Ancaq zaman keçdikcə sistemlər mürəkkəbləşmiş, çoxistifadəçili mühitlər mümkün olmuşdur. Eyni zamanda uzaqdan giriş imkanlarının zamanla genişlənməsi təhlükəsizlik risklərini daha da artırmışdır. Məhz bu səbəblərdən təhlükəsizlik siyasətlərinin formal qaydalar şəklində ifadə olunması və nəzarət mexanizmlərinin sistemləşdirilməsi zərurət halına gəlmişdir. Beləliklə də, klassik modellər bu ehtiyacları müəyyən zaman aralığı üçün ödəmişdir.

Ancaq daim inkişaf bu modelləri də geridə qoymuşdur. Bir neçə il bundan əvvələ qədər təhlükəsizlik modelləri klassik və müasir olmaqla iki yerə bölünürdü. Klassik modellər statik və formal qaydalarla təhlükəsizliyi təmin etdiyi halda, inkişaf sayəsində dinamik və mürəkkəb sistemlər üçün müasir modellər təklif olunmuşdur. Təbii ki, bu “müasirlik” süni intellektin müasir dünyada yerini tutmasına qədər öz əksini tapıb. Artıq təhlükəsizlik modellərinin müasir inkişaf istiqamətləri deyildikdə süni intellektin informasiya təhlükəsizliyinə inteqrasiyası nəzərdə tutulur. Daha yaxşı müqayisə üçün klassik modellərdən ən məşhur sayılan 2 modelə kiçik bir nəzər yetirək :

1. Bell-LaPadula modeli. Bu model məlumatın məxfiliyin qorunmasına yönəlmiş modeldir və ən çox hərbi və dövlət sistemlərində məxfi məlumatın qorunması üçün tətbiq edilmişdir. Bu modelə görə sistemdə iki fayl var : məxfi → gizli və qeyri-məxfi → gizli olmayan.

Və eyni şəkildə iki istifadəçi var : gizli fayllara əlçatanlıq səviyyəsində olanlar → gizli olanlar və gizli olmayanlara əlçatanlıq səviyyəsində olanlar → gizli olmayanlar. Beləliklə sistem bu anlayışlar əsasında iki mühüm qaydanın - oxuma və yazmaya dair , tətbiqini ehtiva edir :

1. Sadə təhlükəsizlik qaydaları (xüsusiyyəti): gizli olmayanlar gizli faylda verilənləri oxuya bilməz, bu qayda gizli məlumatlara sadəcə uyğun səviyyədəki şəxslərin əlçatanlığını təmin edir;

2. * qaydası (xüsusiyyəti): gizli olanlar qeyri-gizli faylda yazı bilməz. Həqiqətən də bu qayda təmin edir ki, səhvən və ya qəsdən gizli məlumatlar qeyri-gizli məlumatların daxilinə köçürülməsin.

2. Biba modeli. Bell-LaPadula modelinin çatışmazlıqlarından ilham alınaraq yaradılmışdır. Belə ki, Bell-laPadula modeli məxfiliyi təmin edirdi, lakin bütövlüklə bağlı bir nəzarət təqdim etmirdi. Biba modeli də özündə əks etdirdiyi iki əsas qayda ilə məhz bu bütövlüyə yönəlmişdir :

1. Bütövlük aksiomu - no write up : bu qaydaya görə heç bir istifadəçi öz səviyyəsindən daha yüksək səviyyədəki məlumatı dəyişdirə və ya əlavələr edə bilməz. Beləliklə məlumat “çirklənməsi”nin qarşısı alınmış olurdu.

2. Sadə bütövlük aksiomu - no read down : burada isə istifadəçi öz səviyyəsindən aşağı məlumatları oxuya bilməz. Daha sadə şəkildə desək, istifadəçi yalnız etibar etdiyi və ya etibar oluna bilən səviyyədəki məlumatları oxumalıdır.

Bu və bu kimi klassik təhlükəsizlik modelləri informasiya təhlükəsizliyinin təmin olunmasında mühüm rol oynasalar da, onların əsasən statik, qayda və səviyyə əsaslı yanaşmalara söykənməsi müasir və dinamik kibertəhlükə mühitində müəyyən məhdudiyyətlər yaradır. Bu modellər sistem davranışını və anomaliyaları təhlil etmək qabiliyyətinə malik deyildir, bu səbəbdən yeni və əvvəlcədən məlum olmayan sıfır-gün (zero-day) hücumlarının, eləcə də uzunmüddətli və gizli xarakter daşıyan APT hücumlarının aşkarlanmasında yetərsiz qalır. Stabil qaydalarla işlədiklərindən konteksti anlamır və yanlış neqativ/yanlış pozitiv nəticələrə səbəb ola bilirlər, bu isə normal fəaliyyətin təhlükə kimi qiymətləndirilməsi, hücumun isə aşkarlanmaması kimi problemlərə səbəb ola bilər. Eyni zamanda, real vaxt rejimli adaptasiya və böyük verilənlərin analizi imkanlarının olmaması onların effektivliyini daha da məhdudlaşdırır.

Qeyd olunan məhdudiyyətlər və problemlər aydın bir şəkildə göstərir ki, ənənəvi yanaşmalar müasir kibertəhlükələr qarşısında kifayət qədər effektiv deyil və bu sahədə daha çevik, adaptiv, öyrənə bilən və real vaxt rejimində qərar qəbul etmə qabiliyyətinə malik olan yeni yanaşmaların tətbiqi vacib bir məsələdir. Bu baxımdan, süni intellekt → Artificial Intelligence (AI) əsaslı yanaşmalar və onun alt istiqamətləri olan maşın öyrənməsi → Machine Learning (ML) və dərin öyrənmə → Deep Learning (DL) metodları, həmçinin təbii dil emalı → Natural Language Processing (NLP) , kompüter görməsi → Computer Vision (CV) və Generativ AI (GenAI) informasiya təhlükəsizliyi sahəsində mühüm və perspektivli istiqamətlərdən biri kimi formalaşmışdır.

AI insan intellektinə xas olan öyrənmə, qərarvermə və problem həll etmə qabiliyyətlərinin komputer sistemləri tərəfindən təqlid edilməsinə imkan verən texnologiyalar toplusudur. Bu yanaşma mürəkkəb sistemlərdə belə qeyri-müəyyənlik şəraitində optimal qərar qəbulunu təmin edir. AI informasiya təhlükəsizliyi sahəsində əsasən böyük həcmli verilənlərin analizi və anomaliyaların aşkarlanması üçün istifadə olunur. Klassik metodlar kimi statik qaydalarla məhdudlanmadığından dəyişən mühitə uyğunlaşa bilir, bu isə dinamik və daim inkişaf edən kibertəhlükələr mövzusunda böyük əhəmiyyət kəsb edir. Eyni zamanda AI müxtəlif mənbələrdən daxil olan məlumatları sintezləyərək daha effektiv və çoxşaxəli analiz imkanları təmin edir.

Süni intellektin praktik tətbiqi onun alt istiqamətləri olan ML və DL metodları vasitəsilə həyata keçirilir. Bu metodlar verilənlər əsasında öyrənmə və mürəkkəb nümunələrin aşkarlanması ilə informasiya təhlükəsizliyi sahəsində daha effektiv, uyğun həllərin formalaşmasına şərait yaradır.

ML süni intellektin alt sahəsi kimi sistemlərin verilənlər əsasında öyrənməsi və nəticədə öz fəaliyyətini avtomatik şəkildə təkmilləşdirməsinə imkan verən yanaşmadır. Bu yanaşmada alqoritmlər əvvəlcədən sərt şəkildə proqramlaşdırılır, verilənlərdə mövcud olan qanunauyğunluqlar və nümunələr aşkar edilir. İnformasiya təhlükəsizliyində ML metodları əsasən anomaliyaların aşkarlanması, şəbəkə trafik analizi və hücumların identifikasiyası üçün tətbiq olunur. Xüsusilə nəzarətsiz (unsupervised) öyrənmə üsulları sayəsində yeni və naməlum hücumların, ən əsası isə “zero-day” təhdidlərin müəyyən edilməsində olduqca effektivdir. ML modelləri zaman keçdikcə yeni verilənlər əsasında adaptiv bir şəkildə yenilənir. Bu isə onları dinamik və dəyişkən kibermühit üçün daha uyğun edir. Nəticə etibarilə, ML yanaşmaları ənənəvi qayda əsaslı sistemlərlə müqayisədə daha çevik və dəqiq nəticələr təqdim edir.

DL ML-in daha inkişaf etmiş alt sahəsidir. O çoxqatlı neyron şəbəkələr vasitəsilə mürəkkəb və yüksək ölçülü verilənlərin analizini həyata keçirir. Bu yanaşma xüsusilə böyük verilənlər (big data) üzərində effektiv işləmə təmin edir. DL modelləri verilənlərdən xüsusiyyətləri avtomatik şəkildə çıxarma qabiliyyətinə malikdir və bu da insan müdaxiləsini minimuma endirilməsinə əhəmiyyətli dərəcədə təsir edir. İnformasiya təhlükəsizliyində bu metodlar şəbəkə trafik analizi, zərərli proqramların aşkarlanması və istifadəçi davranışlarının modelləşdirilməsi kimi sahələrdə geniş tətbiq olunur. DL mürəkkəb və çoxmərhləli hücumların, ən əsası APT (Advanced Persistent Threat) tipli təhdidlərin aşkarlanmasında yüksək səmərəlilik göstərir. Həmçinin bu modellər real vaxt rejimində də böyük həcmli məlumatları emal etmək qabiliyyətinə malikdir. Beləliklə, DL yanaşmaları informasiya təhlükəsizliyi sistemlərinin daha dərin və kompleks səviyyədə təhlil aparmasına imkan yaradan əhəmiyyətli yanaşmalardır.

NLP AI-nin digər vacib alt sahəsi olub, mətnlə ifadə olunan məlumatların avtomatik təhlilini və mənalandırılmasını təmin edir. İnformasiya təhlükəsizliyi sahəsində NLP phishing, sosial mühəndislik hücumları və zərərli e-maillərin aşkarlanmasında xüsusilə geniş tətbiq olunur. Bu yanaşmada modellər mətnin semantik və sintaktik xüsusiyyətlərini analiz edir, şübhəli və potensial zərərli davranışları müəyyən edir. Misal üçün, NLP əsasında qurulmuş sistemlər “zero-link” phishing e-maillərini, fırıldaqçı mesajları və şirkət daxilindəki şübhəli kommunikasiya nümunələrini aşkar edə bilər. NLP insan əməyini minimuma endirir ki, bu da real vaxtda təhlükəsizlik sistemlərinin qərarvermə prosesinə dəstək verir və risklərin daha operativ idarə olunmasına imkan yaradır.

CV isə vizual məlumatların emalını təmin edərək informasiya təhlükəsizliyi üçün əlavə avantaj təmin edir. CV modelləri şəbəkə trafik, veb sahifələr və bu kimi vizual verilənlərdən təhlükəli nümunələri aşkarlaya bilər. Misal üçün, phishing saytlarının ekran görüntülərinin təhlili və ya GAN-lar vasitəsilə sintetik hücum nümunələrinin yaradılması, CV-nin praktiki tətbiqlərinə aiddir. Bu yanaşma, klassik qayda əsaslı sistemlərin əhatə edə bilmədiyi vizual təhdidlərin aşkarlanmasına imkan yaradır və kiberhücumların daha geniş spektrini əhatə edir.

Generative AI (GenAI) informasiya təhlükəsizliyində süni intellektin tətbiq imkanlarını daha da genişləndirir. Bu yanaşma, xüsusilə məlumat çatışmazlığı və nadir hücum ssenarilərinin öyrədilməsi məsələlərində əvəzsiz rol oynayır. Generativ rəqib şəbəkə (GAN) və avtokodlayıcı (autoencoder) kimi generativ modellər, zərərli trafik nümunələrinin və nadir zərərli proqram təminatı tiplərinin sintezini həyata keçirərək, şəbəkə səviyyəsində müdaxilələrin aşkarlanması sistemi (NIDS) və müdaxilənin aşkarlanması sisteminin (IDS) öyrədilməsində və test edilməsində kritik əhəmiyyət daşıyır. GenAI, eyni zamanda, təhlükəsizlik sistemlərinin adaptivliyini artıraraq yeni və inkişaf edən hücumları proaktiv şəkildə aşkar etməyə imkan verir.

AI əsaslı texnologiyalar informasiya təhlükəsizliyi sahəsində yuxarıdakı həllərlə bir çox problemin aradan qaldırılmasına təkan versə də, onların qərarvermə mexanizmi “qara-qutu” kimi qəbul edilirdi. Bu isə insanların qərarı anlamasında və etibar etməsində çətinlik yaradırdı. Təbii ki, bu problemin də həlli üzrə bir çox araşdırmalar edilmiş, nəticədə isə izah edilə bilən süni intellekt → eXplainable AI (XAI) və Responsible AI (RAI) yanaşmaları irəli sürülmüşdür.

XAI süni intellekt sistemlərinin qəbul etdiyi qərarların səbəblərini izah etməyə yönəlmiş bir yanaşmadır. Süni intellekt modelləri, ən əsası DL əsaslı sistemlər, çox vaxt “qara qutu” kimi fəaliyyət göstərir, buna görə də onların qərar mexanizmləri istifadəçi üçün aydın olmaya bilər. XAI isə bu problemi aradan qaldırmaq üçün modelin hansı səbəblərə əsaslanaraq nəticə çıxardığını izah edir. Bu yanaşma həm lokal - ayrı-ayrı qərarların izahı, həm də global - modelin ümumi davranışı, səviyyədə tətbiq oluna bilər. XAI metodları ilə modelin gəldiyi qərara təsir edən əsas xüsusiyyətlər müəyyən edilir. Bu isə təhlükəsizlik sistemlərində daha şəffaf və etibarlı qərarverməni təmin edir. XAI informasiya təhlükəsizliyi sahəsində, xüsusilə də anomaliyaların aşkarlanması, zərərli proqramların analizi və intruziya aşkarlama sistemlərində qərarların izahı baxımından çox mühüm rol oynayır. Bu yanaşma sayəsində istifadəçilərin süni intellekt sistemlərinə olan etimadı artırır və qərarların əsaslandırılması mümkünləşir.

RAI isə süni intellekt sistemlərinin etik, hüquqi və sosial baxımdan məsuliyyətli və düzgün bir şəkildə tətbiq olunmasını təmin edən yanaşmadır. Bu yanaşmada məqsəd AI sistemlərinin yalnız effektiv deyil, eyni zamanda ədalətli, təhlükəsiz və qanunvericiliyə uyğun fəaliyyət göstərməsini təmin etməkdir. RAI-nin əsas prinsipləri sistemlərin diskriminasiyaya yol verməməsi, məlumatların məxfiliyinin qorunması və qərarların məsuliyyətli şəkildə qəbul edilməsidir. İnformasiya təhlükəsizliyi sahəsində RAI yanaşması AI modellərinin etibarlı istifadəsini, risklərin minimuma endirilməsini və istifadəçi hüquqlarının qorunmasını təmin edir.

Klassik modellər və AI əsaslı yanaşmaların müqayisəsi :

Meyar	Klassik modellər	AI əsaslı yanaşmalar
İş prinsipi	Qayda/siyasət əsaslı	Verilənlər əsasında öyrənmə
Şəffaflıq	Yüksək səviyyədə	Nisbətən aşağı
Yeni təhdidlərin aşkarlanması	Məhdud imkanlar	Yüksək səviyyədə
Anomaliyaların aşkarlanması	Məhdud imkanlar	Avtomatlaşdırılmış sistem
İnsan müdaxiləsi	Maksimum tələb olunur	Minimuma endirilmişdir
Emal olunan məlumat	Məhdud həcmli	Böyük verilənlər(big data)
Elastiklik	Sərt qaydalar	Dinamik və adaptiv sistem
Qərarvermə	Əvvəlcədən təyin olunmuş qaydalara əsaslanır	Öyrənmə əsalı
Hesablama mürəkkəbliyi	Nisbətən aşağı	Yüksək
Tətbiq sahəsi/mühiti	Statik və sabit	Kompleks və dinamik

Mənbə : Müəllif tərəfindən hazırlanmışdır

Yuxarıdakı müqayisədən də göründüyü kimi, klassik informasiya təhlükəsizliyi modelləri sadə və şəffaf struktura malikdirlər və bu onları etibarlı edir, lakin onların əsas çatışmazlığı dəyişən və mürəkkəb kibertəhlükələrə qarşı zəif uyğunlaşma qabiliyyətidir. AI əsaslı yanaşmalar isə verilənlər əsasında öyrənmə və adaptasiya xüsusiyyətləri vasitəsilə həm məlum, həm də naməlum təhdidlərin aşkarlanmasında daha effektiv nəticələr təqdim edir. Xüsusilə ML və DL metodları böyük həcmli məlumatların analizi və anomaliyaların müəyyən edilməsində böyük əhəmiyyətə malikdir. Lakin bu yanaşmaların “qara qutu” xarakteristikası etibar və hüquqi məsələlərdə çətinlik yarada bilər, bu çətinliklər isə XAI və RAI ilə aradan qaldırılır.

Nəticə

Müasir rəqəmsal dövrdə informasiya təhlükəsizliyi sahəsində baş verən dəyişikliklər və kibertəhlükələrin mürəkkəbləşməsi ənənəvi təhlükəsizlik modellərinin bu təhdidlər qarşısında təkbaşına kifayət etmədiyini göstərir. AI əsaslı yanaşmalar, xüsusilə ML, DL, NLP və digər texnologiyalar vasitəsilə daha çevik, adaptiv və effektiv həllər təqdim edir. Eyni zamanda, XAI və RAI kimi yanaşmalar isə bu sistemlərin şəffaflığını, etibarlılığını, hüquqi və etik uyğunluğunu təmin edərək onların real mühitdə tətbiqini daha da mümkün edir. Nəticə etibarilə, informasiya təhlükəsizliyinin gələcək inkişaf istiqaməti süni intellekt texnologiyalarının mövcud sistemlərə daha geniş integrasiyası və onların düzgün istifadəsi ilə sıx bağlıdır.

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Economic Sciences

THE IMPACT OF CROSS-CULTURAL DIFFERENCES ON THE EFFECTIVENESS OF COLLEGE TEACHER TEAM COLLABORATION

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Introduction

The education system is undergoing significant changes related to the processes of globalization, internationalization of the labor market and increased academic mobility. In this regard, colleges are becoming centers of intensive intercultural interaction, where teachers from different countries and regions join professional teams. Cultural diversity in teaching staff is not only a natural characteristic of the educational environment, but also an important factor affecting the quality of communication, role allocation, managerial decision-making and the overall effectiveness of professional activities.

Despite the growing interest in issues of intercultural communication and collaboration among educators, there are still significant gaps in the scientific literature.

Firstly, it is not well understood how cultural differences manifest themselves in the daily professional activities of college teachers. Many studies focus on the university environment, ignoring the specifics of colleges, where communication and coordination of actions are more practical and cooperative.

Secondly, few studies have been devoted to comparing the intercultural characteristics of teachers in countries with different educational systems and historical traditions.

Thirdly, there is a lack of comprehensive research linking the cultural attitudes of teachers with the effectiveness of their professional cooperation, including the allocation of responsibilities, methods of interaction, conflict resolution mechanisms and the perception of colleagues.

The choice of China and Kazakhstan as objects of comparative analysis is reasonable and relevant for a number of reasons. Both countries are characterized by the growth of academic mobility, the expansion of international educational programs and the active involvement of foreign teachers, including in the system of technical and vocational education. At the same time, Kazakhstan and China have different cultural traditions, management models and approaches to education, which makes their comparison methodologically valuable.

China is an example of a centralized system with a strong emphasis on collectivism, hierarchy, and discipline. At the same time, Kazakhstan combines elements of the post-Soviet educational paradigm with the active implementation of Western models and a focus on flexibility, individual approach and management modernization.. This study examines the impact of cultural

and institutional differences on the effectiveness of intercultural interaction between college teachers.

The purpose of the study is to identify the factors determining the success of the joint work of college teachers and to identify the factors contributing to successful intercultural cooperation.

To achieve this goal, the following tasks were defined:

1. To analyze theoretical approaches to the study of intercultural communication and professional interaction in teaching groups.
2. To identify the key intercultural differences characteristic of teachers working in a multicultural college environment.
3. To consider the influence of cultural attitudes on the peculiarities of communication, coordination of actions, the distribution of professional roles and the effectiveness of joint activities.

Identify typical problems and conflicts that arise in intercultural teaching groups and assess their impact on the educational process.

To develop recommendations for optimizing intercultural interaction between college teachers in China and Kazakhstan.

The scientific novelty of the research lies in a comprehensive analysis of the mechanisms of intercultural interaction between college teachers and the identification of factors determining the effectiveness of professional cooperation. The study expands the understanding of the influence of cultural background on the nature of teamwork and suggests new approaches to managing intercultural communications in educational institutions.

The theoretical significance of the research lies in the deepening and systematization of knowledge about intercultural communication in the pedagogical field, as well as in clarifying the conceptual framework and identifying patterns of intercultural cooperation in professional groups. The results of the study can be useful for further scientific research in the field of international educational management.

The practical significance of the research lies in the development of recommendations that can be used to create adaptation programs for foreign teachers, teach intercultural competence and form effective management models in multinational teaching teams. The proposed measures will improve the quality of communication, reduce the risk of conflict and create a more favorable educational environment in colleges in Kazakhstan and China.

Literature review

In the context of the internationalization of education and the growing academic mobility of teachers, intercultural approaches are actively developing in the educational environment. Modern colleges are becoming multicultural spaces where the effectiveness of professional interaction is determined not only by professional skills, but also by culturally determined behaviors.

Based on modern research, classical cultural models that allow analyzing differences between countries are excluded. The most widely used research is by G. Hofstede, who identified influential cultural parameters in the work process, such as power distance, individualism–collectivism, and avoidance of uncertainty[1]. These parameters directly affect decision-making models and the style of pedagogical interaction.

According to Hofstede, a culture with a high power distance often demonstrates a formalized communication style and rigid hierarchy, which can complicate the equal cooperation of teachers[2].

E. Hall, who developed the concept of combining high- and low-context cultures, showed that the difference in the ways of transmitting information (direct and tunnel style) affects the effectiveness of communication[3].

Nevertheless, Hall did not study teaching groups as separate professional communities; it is critical for the contextual communication of a teacher.

F. Trompenaars and C. Hampden-Turner, who proved that universalism–particularism, specificity–diffusivity and emotionality of culture determine working interaction and various roles[4]. Their models are practically not used to analyze intercultural teaching teams, where relationships and roles are formed based on a specific process.

In addition to conceptual models, Western authors who study intercultural interaction in educational groups contribute to the development of this field[5].

A. Vahed explores the influence of cultural factors on the collaboration of educators in international programs. He notes that the diversity of cultures can enhance the team's innovation. His findings confirm that multipedagogic groups use a wider range of solutions[6].

H. Spencer-Oatey argues that cultural norms of behavior and expectations regarding professional roles directly affect the quality of pedagogical interaction[7]. Author emphasizes the innovativeness of intercultural competence as a key factor in the success of cooperation.

Research in this area focuses on general aspects of intercultural communication, while issues of role allocation and coordination of actions within teaching teams in colleges remain insufficiently studied.

J. Braslauskas developed a model for the formation of intercultural competence of a teacher, emphasizing that the lack of intercultural skills creates barriers and conflicts. J. Braslauskas does not propose practical strategies for managing intercultural interactions in institutions of secondary vocational education, which creates a gap in research[8].

Y.Wang, Q. Chen analyzes the cross-cultural differences between Chinese and Western teachers, noting that differences in the perception of hierarchy and responsibility hinder collective decision-making[9]. Y. Wang, Q. Chen considers interaction only between Chinese teachers and their Western colleagues, without paying attention to cooperation between Central Asian countries, for example, Kazakhstan.

Despite the availability of fundamental research, there are a number of areas in the literature that remain insufficiently studied and are important for this work.

In particular, cross-cultural differences among college teachers have not been sufficiently studied, although this area is recognized and requires study in terms of organizational and pedagogical features.

Classical cultural models such as the Hofstede, Hall, and Trompenaars models are rarely used for practical analysis of the situation within teaching teams, especially in the context of secondary professional education.

There are also almost no studies revealing the influence of cultural factors on various roles, coordination of actions and professional communication among college teachers.

In addition, the issues of intercultural interactions with an external source remain insufficiently studied, without analyzing the causes, types, and ways to resolve them in teaching groups.

There are practically no comparative studies of intercultural interaction between teachers from Kazakhstan and China, despite active educational cooperation and the growing exchange of specialists between these countries.

A review of the literature shows that cultural differences have a significant impact on the professional interaction of managers. However, the analysis also reveals important gaps in theoretical and practical knowledge about the need for comprehensive research on intercultural interaction between teachers in colleges in Kazakhstan and China.

Research methodology

To investigate the distinctive characteristics of personalized learning in China and Kazakhstan, two complementary methods were chosen in this method: a comparative analysis

and a sociological survey. The comparative analysis method enables us to organize and contrast the practices of personalized learning in both countries, pinpointing similarities and dissimilarities in the approaches to individualization, as well as evaluating the influence of governmental reforms, digital technologies, and educational policies on the requirements of relevant student trajectories. This approach was selected because it allows us to compile and present the findings of theoretical and empirical research outlined in the literature, thus creating a comprehensive overview of the national models of higher education.

The second method, a sociological investigation, was employed to gather initial information about the perception of personalized educational approaches among university students and instructors in China and Kazakhstan. The survey enables us to assess the degree of satisfaction with educational paths, which serves as a measure of the success of students and teachers in personalizing their work, as well as to evaluate the efficacy of the digital platforms utilized and the adapted mathematical programs. This method was selected because it allows us to collect both quantitative and qualitative data that directly reflect the practical impact of individualization on the learning process and students' motivation, as well as to identify signs and potential avenues for its further advancement.

The implementation of these methods requires a thorough investigation: a comparative examination forms the theoretical framework and enables us to discern common patterns and disparities between the two nations, while a sociological investigation provides empirical validation of these patterns at the level of participants in the educational process. These combined approaches not only describe and consider diverse individualization practices, but also assess their efficacy from the perspectives of students and educators, thereby enhancing the practical impact of research.

Results and discussion

To study cross-cultural views on the effectiveness of teamwork, college teachers used two methods: a sociological survey and a comparative analysis. Working on the tasks set, the results were obtained, demonstrating both quantitative and qualitative aspects of intercultural interaction.

The survey was conducted among 60 college professors from China (n=30) and Kazakhstan (n=30). A survey of questions about the perception of intercultural languages, work experience in multicultural teams, barriers to communication and satisfaction with teamwork.

Table 1 – Survey results

Survey	Professors from China	Professors from Kazakhstan
How often do cultural differences affect your collaboration with colleagues?	80%	65%
Do you experience difficulties communicating with colleagues from a different culture?	45%	50%
How important is intercultural competence to you?	90%	85%
How often do conflicts arise due to cultural differences?	20%	25%
Are you satisfied with the collaboration in your multicultural team?	75%	70%

The source was compiled by the author

The findings of the survey can be better comprehended when they are connected to established cultural dimensions that influence communication, expectations, and behavior in collaborative environments. The higher proportion of Chinese professors (80%) who report that cultural differences frequently impact collaboration compared to their Kazakhstani counterparts (65%) can be explained by Hofstede's concept of collectivism and the high power distance in China. In collectivist cultures, the importance of group harmony and shared norms is paramount, making

any deviations in communication style or expectations more noticeable. Kazakhstan, while also being relatively collectivist, exhibits a more diverse cultural landscape, influenced by both nomadic traditions and post-Soviet educational norms, which may mitigate the perceived impact of cultural differences in day-to-day teamwork.

The communication challenges reported by 45% of Chinese and 50% of Kazakhstani professors can be attributed to the differences in communication styles between high-context and low-context cultures. China is typically classified as a high-context culture, where the meaning is conveyed implicitly, and building relationships is paramount. Kazakhstan, on the other hand, combines high-context communication with more direct, low-context patterns, which are influenced by the Soviet administrative culture. This blend of communication styles may increase the likelihood of misunderstandings in multicultural interactions, which is why Kazakhstani professors report slightly higher communication difficulties.

The significance of intercultural proficiency, which is valued at 90% in China and 85% in Kazakhstan, aligns with the global perspective and long-term outlook in Hofstede's framework. China, with its strong emphasis on long-term orientation, strategically incorporates intercultural competencies into professional growth as part of its ongoing educational reforms and internationalization initiatives.

Kazakhstan also acknowledges the importance of intercultural proficiency, but the institutional frameworks for developing these skills are less developed, resulting in a slightly lower but still substantial percentage.

The relatively infrequent occurrence of disputes arising from cultural disparities (20% in China, 25% in Kazakhstan) is in line with the norms of conflict avoidance prevalent in collectivist and relationship-oriented cultures. In China, where preserving harmony is a fundamental cultural value, open conflict is typically avoided, particularly in professional contexts. In Kazakhstan, while harmony is also cherished, workplace communication can occasionally reflect more direct or hierarchical Soviet-influenced norms, which may slightly increase the likelihood of conflicts.

The overall level of satisfaction with multicultural teamwork, which was 75% among Chinese participants and 70% among Kazakhstani participants, also reflects cultural patterns. The stronger emphasis on structured teamwork, hierarchical clarity, and professional roles in China may contribute to smoother coordination and higher satisfaction rates.

The satisfaction level among Kazakhstani participants is also high, but variations in communication styles and less formalized teamwork structures may account for the slightly lower percentage.

By examining these results in relation to major cultural dimensions, it becomes clear that the differences in teamwork effectiveness are not arbitrary but rooted in deeper cultural logic. The findings demonstrate how communication norms, value systems, and institutional cultures influence professors' experiences and perceptions of cross-cultural collaboration.

To enhance our comprehension of the distinctions and peculiarities in teacher-student communication, a comparative examination was performed, drawing upon the well-known Hofstede cultural dimensions (indicators of individualism, power distance, and uncertainty avoidance)(table 2).

Table 2 – Key Characteristics of Cultural Interaction among Teachers

Indicator	China	Kazakhstan
Individualism / Collectivism	Collectivism (low individualism)	Medium level of collectivism
Power Distance	High, respect for hierarchy	Medium, more flexibility in relationships
Uncertainty Avoidance	High, preference for clear instructions	Medium, willingness for flexible solutions

Communication Style	Informal, indirect	Direct, open
Decision-Making Preferences	Consensus through senior members	Collective discussion, equal participation

The source was compiled by the survey results

A deeper interpretation of the survey results becomes feasible when they are considered in conjunction with Hofstede's cultural dimensions and the comparative indicators outlined in Table 2. The patterns observed in the responses of Chinese and Kazakhstani college professors are not arbitrary but rather reflect the underlying cultural framework that influences professional communication, teamwork dynamics, and attitudes towards cross-cultural engagement.

The significant proportion of Chinese teachers (80%) who perceive cultural disparities as a frequent impediment to collaboration is directly linked to China's pronounced collectivist culture and high power distance. In collectivist and hierarchical societies, as described by Hofstede, the emphasis is placed on harmony, clear roles, and respect for authority. Consequently, any deviation from shared norms becomes more apparent.

In contrast, Kazakhstani educators (65%) report a somewhat lower awareness of cultural differences, as Kazakhstan exhibits a moderate level of collectivism and a medium power distance. This flexible hybrid culture, shaped by both nomadic heritage and Soviet administrative traditions, makes Kazakhstani academic communication more adaptable and less reliant on norms, reducing the perceived significance of cultural differences.

Communication issues reflect a similar cultural pattern. Chinese educators (45%) encounter obstacles that are in line with China's high-context, indirect communication style, where meanings are subtly conveyed and building relationships is emphasized.

However, Kazakhstani educators (50%) experience slightly more communication difficulties, possibly due to Kazakhstan's blend of direct, low-context communication and residual hierarchical expectations from Soviet pedagogical culture. These contrasting communication norms can lead to miscommunications when interacting across cultures.

The strong focus on intercultural competence in both groups — 90% in China and 85% in Kazakhstan — reflects broader educational trends identified in the literature. In Kazakhstan, where the institutional frameworks are less systematic, the percentage is slightly lower, reflecting the country's recognition of the importance of intercultural skills.

The low incidence of conflict reported by both groups (20% in China; 25% in Kazakhstan) can be attributed to the conflict avoidance norms prevalent in collectivist cultures. In China, where maintaining harmony is a fundamental social value, conflict is typically addressed indirectly or prevented through strict hierarchical structures. In Kazakhstan, the slightly higher conflict rate may be a result of a more open and direct communication style, coupled with less formalized conflict management systems.

Similarly, the high level of satisfaction with teamwork (75% in China; 70% in Kazakhstan) can be attributed to cultural tendencies. In China, satisfaction is enhanced by the clear structure, hierarchical coordination, and established teamwork norms that are common in collectivist, high-power-distance contexts. In Kazakhstan, while satisfaction remains high, it is slightly lower, likely due to the more fluid team structures and the absence of standardized mechanisms for supporting multicultural collaboration.

The findings of this study, combined with the cultural characteristics presented in Table 2, align with existing research from both countries. Chinese scholars have consistently emphasized the importance of hierarchy, collectivism, and long-term orientation in shaping communication, while Kazakhstani authors have highlighted the role of institutional hybridity, evolving digital practices, and the gradual development of intercultural competence within post-Soviet educational frameworks.

The empirical results of this study reinforce the patterns identified in the literature and provide new insights into how different cultural contexts influence teamwork practices among college instructors.

To sum up, by combining empirical data with cultural theory, the research provides a more detailed insight into how cultural environments influence professional cooperation and outlines strategies for improving intercultural performance in both nations.

Combining the data from the sociological survey and comparative analysis allows us to draw several key conclusions:

Intercultural differences really affect the teamwork of teachers, but with high intercultural competence, teams are able to successfully adapt.

Chinese teachers demonstrate a higher willingness to obey the organizational hierarchy, which reduces the likelihood of conflict, but may limit initiative in decision-making.

Kazakhstani teachers are prone to open interaction, which increases participation in discussions, but sometimes leads to misunderstandings when interacting with collectivistic ally oriented colleagues.

The effectiveness of teamwork is determined not only by individual characteristics, but also by the organizational culture of the college, the availability of conflict resolution mechanisms and support for intercultural interaction.

Conclusion

The conducted research revealed that cultural differences have a significant impact on the effectiveness of the joint work of college teachers. The results of the sociological survey and comparative analysis showed that cultural aspects such as power distance, communication styles, and decision-making preferences have a direct impact on the interaction between Chinese and Kazakhstani educators.

Teachers from China, who are characterized by a high power distance and a pronounced tendency to collectivism, tend to avoid open conflicts and prefer hierarchical coordination. At the same time, teachers from Kazakhstan, who prefer open and direct communication, actively participate in discussions and strive for equal decision-making, which can sometimes cause difficulties when interacting with colleagues from more collectivist cultures.

It is important to emphasize that successful cooperation in multicultural teaching groups depends not only on cultural values. An important role is played by the level of intercultural competence, the availability of organizational support mechanisms, as well as tools for conflict prevention and resolution.

Teachers' high awareness of the importance of intercultural competence indicates a willingness to adapt and interact effectively, despite cultural differences.

To improve the quality of collaboration in an environment of cultural diversity, colleges should implement specific practical measures aimed at developing intercultural communication skills. These measures include:

Intercultural communication trainings aimed at developing communication strategies, conflict prevention, and cultural awareness;

Adaptation programs for new teachers aimed at mastering cultural norms, expectations of the organization and principles of teamwork.

Master classes and joint projects that promote the exchange of experience and strengthen professional ties between representatives of different cultures.

Regular reflection sessions, during which teachers can discuss emerging difficulties and share successful practices.

A mentoring system in which teachers from different cultural groups work in pairs and teach each other.

Despite the significance of the results, the study has a number of limitations.

First, the sample of 60 respondents limits the possibility of generalizing the results to all colleges in China and Kazakhstan.

Secondly, the survey is based on the subjective assessments of the respondents, who may be subject to personal biases or the desire to give socially desirable answers.

Thirdly, the study focuses on three cultural dimensions (individualism, collectivism, power distance, avoidance of uncertainty), ignoring other important factors such as orientation towards long-term planning or the allocation of gender roles.

The prospects for future research include expanding the sample, reaching faculty from different regions and types of colleges, as well as conducting long-term research on the dynamics of intercultural competence.

The use of qualitative research methods such as interviews, observation, and an ethnographic approach will allow for a deeper study of the mechanisms of intercultural interaction.

In addition, a promising area is to evaluate the effectiveness of specific educational programs and compare models of interaction in other multicultural educational environments.

Thus, cross-cultural differences should be considered not as an obstacle, but as a resource for strengthening teamwork, stimulating innovation and improving the educational process. The introduction of targeted educational programs, adaptation measures, and structured interaction mechanisms will enhance the effectiveness of cooperation and create an inclusive and productive educational environment.

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VERTICAL INTEGRATION AND MULTI-SOURCING: A CAUSAL ANALYSIS OF BYD'S STRATEGY ON PROCUREMENT COSTS AND SUPPLY CHAIN RESILIENCE

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Introduction

In the context of global competition and the rapid development of technology companies operating in the field of high-tech production, problems arise with the need to optimize procurement costs and ensure the sustainability of supply chains. One example of a successful strategy in this area is BYD, which is actively developing a vertically integrated model and combining it using multiple external sources. This approach allows not only to improve control over key components, but also to reduce the system's dependence on individual sources, and create a more flexible and sustainable supply chain. BYD's strategic decision analysis is relevant because the company has a high growth rate of the global electric vehicle and battery technology market, and its supply chain management model is becoming a benchmark for other manufacturers.

The relevance of the study has led to the need for a deeper understanding of how vertical integration in the United Kingdom with many source purchases can optimize costs, increase the stability of supply chains and reduce the risks associated with market instability. In the context of geopolitical uncertainty, rising prices for raw materials and the study of logistical factors thus become a prerequisite for the development of industrial policy, procurement managers and supervision in the field of management management.

The aim of the study is to conduct a causal analysis of BYD's strategy based on vertical orientation and the use of multiple sources of supply, and to show its impact on optimizing procurement costs and a sustainable supply chain.

To achieve this goal, it is necessary to solve the following tasks: :

To characterize the theoretical foundations of vertical policy and the multitude of sources of methods in modern supply chains.

To analyze the key elements of BYD's vertical entrepreneurial activity and its approach to the formation of a production and procurement system.

To identify the cause-and-effect relationships between the BYD supply strategy used and the reduction of procurement costs.

Assess the impact of multiple procurement sources on the sustainability of the BYD supply chain in the second major risk.

To form conclusions and recommendations on the application of similar strategies of other companies.

The scientific novelty of the study lies in the integrated concept of vertical management and a multi-source procurement model within a single company based on the BYD principle, as well as in identifying specific causal principles, ensuring cost reduction and increasing the sustainability of the supply chain. The novelty lies in the development of an analytical model that reveals the relationship between the leadership structure, supply diversification and the level of sustainability of the procurement system, which allows us to propose new approaches to strategic supply chain management in high-tech industries.

Literature review

Vertical integration and a diverse sourcing approach are fundamental aspects of contemporary supply chain management, particularly in advanced industries such as electric vehicles and battery production[1]. In the realm of scientific inquiry, vertical integration serves as a means of managing the manufacturing process in relation to external sources, while also striving for cost optimization[2].

Studies have shown that companies that adopt vertical integration reap strategic advantages, including enhanced operational efficiency, reduced transactional expenses, and accelerated innovation[3].

In parallel with vertical integration, sourcing from multiple sources is viewed as a means to diversify supply sources, mitigate disruptions, and enhance the resilience of supply chains[4]. Recent studies indicate that a combination of strategies enables organizations to strike a balance between control over crucial elements and maintain adaptability when engaging with long-term suppliers[5].

BYD, the market leader in China for electric vehicles and batteries, employs a hybrid approach to procurement, combining vertical and multi-source strategies.

According to research and independent reports, BYD is actively developing its own production of batteries, electric motors, and body components, while maintaining long-term partnerships with key material suppliers. This approach helps to reduce procurement costs, speed up production, and enhance the resilience of the supply chain in the face of ongoing disruptions, fluctuations in raw material prices, and logistical constraints.

The significance of this study is underscored by the fact that global supply chains are facing challenges due to geopolitical instability, rising commodity prices, and changing consumer preferences. The analysis of successful practices, such as BYD's strategy, provides valuable insights into effective cost management and sustainability enhancement.

Research methodology

To accomplish the goals and thoroughly examine BYD's procurement approach and supply chain sustainability, we employ two fundamental techniques: a cause-and-effect analysis and a comparative analysis. These methods enable us to delve into the underlying rationale behind the company's decision-making processes and assess their efficacy in the context of the fifth global technological contest.

The first method is a cause-and-effect analysis, which examines the direct and indirect relationships between the components of a vertically integrated company, a multi-channel procurement approach, and the actual changes in costs and supply chain sustainability. The application of this approach is supported by the examination of issues related to the need for conceptual indicators, through the production process of key components, the management of energy sources, and the diversification of suppliers. The analysis also considers the strategic implications of BYD's strategy, which includes deep vertical integration, encompassing the production of batteries, electric motors, and electronic components, as well as the use of various categories of indicators for critical materials.. You consistently consider the logical sequence of

«strategy — process — impact — outcome», which enables you to monitor, for instance, how the level of transaction expenses at the manufacturing base contributes to its stability, or how diversifying suppliers mitigates the risks associated with procurement. Furthermore, a causal examination of the findings of the parliamentary inquiry, in light of comparable entities like Tesla or CATL, confirmed the reliability of the outcomes.

The second main method is comparative analysis, which allows us to contrast the BYD shift with the approaches of other cutting-edge manufacturers and existing theoretical models for managing supply chains.

The use of conditional analysis, based on research objectives, helps us determine the degree of uniqueness of the BYD strategy and identify the most effective elements of its integration and procurement policy.

Within the framework of this method, of comparing the parameters of vertical policy, structure, and geography of supplies, depending on international markets, the resilience of supply chains to global risks, and the achieved cost indicators.

When comparing BYD with manufacturers such as Tesla, NIO, or CATL, the following differences:

BYD has a more comprehensive control over the production of batteries and components, offers a wider range of sources for key materials, and has a more stable production system, which shields it from external disruptions.. This method enables us to objectively evaluate the competitiveness of the BYD model and identify which aspects of its strategy can be adapted and implemented in other companies and industries.

The contemporary application of causal and comparative analysis offers a thorough scientific evaluation of the BYD strategy, allowing us to discern patterns, explain the origins of its success, and validate the scientific novelty of research related to the integration of vertical and multi-source models, all within a unified analytical framework.

Results and discussion

As part of the BYD analysis strategy aimed at reducing procurement costs and increasing the sustainability of the supply chain, the study relies on two key methods — causal and comparative-analytical, which allow us to comprehensively disclose the tasks stated in the work and ensure the scientific validity of the conclusions.

The first uses causal analysis to identify the direct and indirect connections between BYD's implemented strategic approaches and their actual influence on procurement effectiveness and supply chain resilience. This approach follows a step-by-step process, starting with the strategic objectives of the company (such as domestic battery manufacturing, self-production of electronic components and power units, diversification of lithium sources and rare earth systems) and progressing to operational changes (reduction of transaction costs, settlements from manufacturing facilities, and acceleration of production processes), ultimately leading to economic and sustainable outcomes (stable production costs, adaptation to market disruptions, and sustainability of sustainability).

In the context of the causal investigation, logical chains are built to demonstrate how vertical integration directly lowers BYD's procurement expenses, while the utilization of multiple suppliers helps to mitigate the risks of disruptions. For instance, the use of proprietary solar panels reduces the price fluctuations that are common in the global lithium-ion component market, and the parallel operation with multiple suppliers helps to slow down production during price changes or logistical issues. These findings align with data from other companies, confirming the reliability of the cause-and-effect relationship(Figure 1).

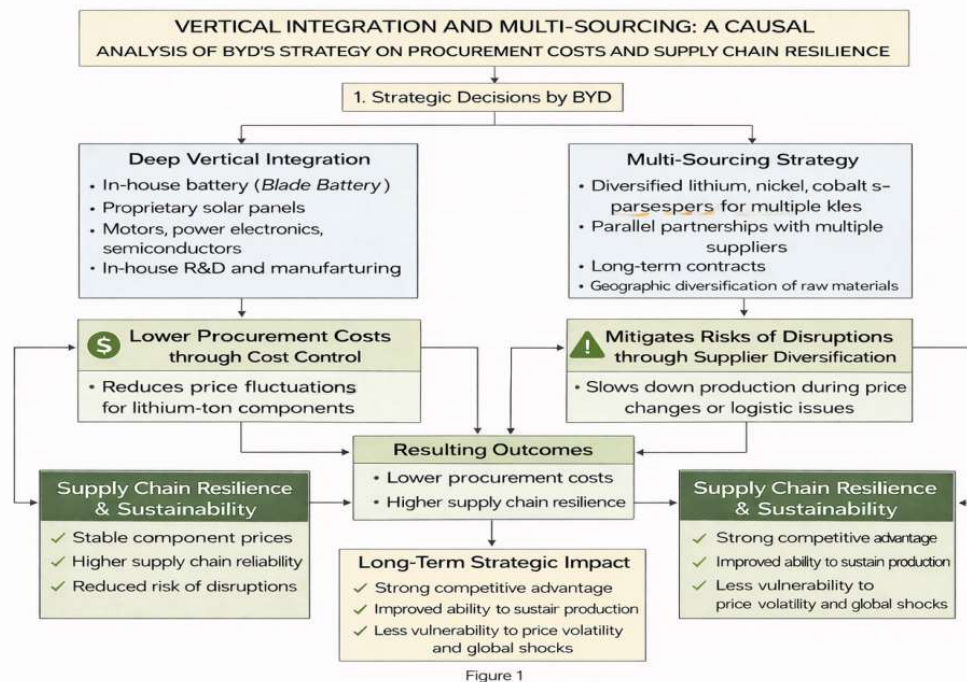


Figure 1. Model of BYD's

The presented graphical model of cause-and-effect relationships reflects BYD's comprehensive strategy for creating a resilient and efficient supply chain, which is based on a deep vertical structure and the sourcing of key resources from multiple suppliers.

The core of this strategy is BYD's decision to reduce reliance on external manufacturers and to ensure technological self-sufficiency. This decision was made in response to market trends, which have led to increased financial risks, market volatility, and the need for control over advanced technologies.

The implementation of vertical integration as a strategic pillar in the models empowers BYD to self-produce all the components of its primary electric vehicle — from the Blade Battery packs to the electric motors, electronic controllers, and software. This is made possible by the existence of in-house research centers. Consequently, the company enjoys a range of advantages, including cost savings, enhanced product quality, enhanced process control, and the ability to scale up production capacity. The reliance on internal components also exposes the company to the risk of price volatility, which is particularly significant in the market for the production of components from renewable sources.

Conversely, the model suggests that BYD's approach is not confined to vertical integration, but rather encompasses a multisourcing strategy. The company collaborates with various suppliers of lithium, nickel, and cobalt, ensuring geographical diversification and securing long-term agreements with resource companies. This approach not only mitigates reliance on any single source but also enables the company to maintain a balanced purchasing strategy, preventing sudden price fluctuations. By distributing the supply chain, BYD can effectively manage resource risks, even during times of economic instability.

The combined influence of vertical radiation and multi-source sourcing results in pronounced operational impacts, which are also factored into the models. A substantial decrease in transaction and logistics expenses minimizes the influence of external factors on production cycles, enhances supply synchronization, and ensures a more stable cost structure. This will enable BYD to swiftly adapt to changes and promptly boost production.

The ultimate goal of all causal relationships is to enhance the resilience of supply chains, minimize subsequent procurement expenses, and gain a competitive edge over rivals. The model demonstrates that such strategic approaches foster long-term operational sustainability for BYD, enabling the company to thrive even in the face of supply disruptions, as it did during the pandemic. Through a combination of tactics, BYD has successfully maintained low costs for electric vehicles, safeguarded itself against economic market fluctuations, and swiftly entered a competitive market, gaining a competitive advantage over economic, fragile, or dependent supply chains.

The second main method is comparative analysis, which makes it possible to compare the BYD shift with the approaches of other high-tech manufacturers and existing theoretical supply chain management models. The use of conditional analysis based on research objectives aimed at determining the degree of uniqueness of the BYD strategy, as well as identifying the most effective elements of its integration and procurement policy. Within the framework of the method of comparing the parameters of vertical policy, structure and geography of supplies, depending on foreign markets, the sustainability of supply chains to global risks, as well as achieved cost indicators. Comparing BYD with manufacturers such as Tesla, NIO or CATL, the following differences are revealed: BYD has deeper control over the production of batteries and components, provides deeper diversification of sources of key materials, and has a more stable production system, which provides it with protection from external shocks. This approach allows us to objectively assess the competitiveness of the BYD model and determine which elements of its strategy can be reworked in other companies and industries(in table 2).

Table 1. Comparison of supply chain management strategies: BYD and competitors

Indicator / Company	BYD	Tesla	CATL	NIO
Depth of Vertical Integration	Very high (batteries, electronics, motors, assembly)	Medium (batteries partially outsourced)	High (battery production, raw materials)	Low (strong dependence on external suppliers)
Procurement Model	Multi-sourcing + in-house production	Limited multi-sourcing	Multi-sourced raw material base	High dependence on external suppliers
Supply Chain Resilience	Very high (control over critical components)	Medium (risks due to external suppliers)	High (control over raw materials)	Low (sensitivity to market and logistics risks)
Procurement Cost Level	Low due to vertical integration	Medium	Medium	High
Degree of Dependence on External Markets	Low	Medium	Medium	High

The source was compiled based on the data [6-10]

The incorporation of comparative analysis into a unified methodology enables us to not only evaluate the absolute performance metrics of BYD's strategy, but also to identify the specific factors that confer the company a unique competitive edge. This includes a deeper level of production integration compared to Tesla, more stable supply chains compared to NIO, and a more diverse raw material base compared to highly specialized manufacturers.

Therefore, both causal and comparative methods are employed within a unified research framework, providing a comprehensive assessment of the BYD strategic model and its impact on procurement costs and supply chain resilience. The combination of these approaches allows us not only to explain the mechanisms of effectiveness, but also to highlight the scientific novelty of the study, which lies in demonstrating the synergistic effect of combining vertical integration and a multi-source procurement model in the context of global uncertainty.

Conclusion

BYD's history serves as a clear illustration of how a combination of deep vertical integration and a diverse sourcing strategy can confer substantial advantages in the face of global competition and unpredictable supply chains. The most striking example is the period of global microchip and battery material shortages in 2020-2022, which disrupted production for automotive companies worldwide.

BYD, unlike many competitors, emerged relatively unscathed from the crisis due to the fact that it manufactured key components for electric vehicles — batteries, semiconductors, and powertrains — internally. BYD's in-house semiconductor division provided the production of critical microchips for inverters, motor control systems, and battery packs, enabling the company to maintain production levels, while Toyota, Volkswagen, Ford, and especially NIO were forced to temporarily halt assembly lines.

Furthermore, BYD has implemented a robust multi-source supply chain for raw materials, in addition to its vertical integration strategy. To this end, the company has proactively diversified its lithium contracts by signing agreements with suppliers from Chile, Australia, and China, as well as investing in its own lithium deposits. This approach has helped BYD mitigate the impact of lithium price fluctuations, which surged by more than six times in 2022, and maintain stable production costs.

Meanwhile, competitors like Tesla were actively adjusting car prices due to the volatility in commodity markets. However, BYD not only maintained the cost of its models but also expanded its market share.

It is noteworthy that BYD, by combining two approaches — vertical integration and diversified sourcing — managed to not only maintain its output levels but also significantly increase them. This achievement was the key to BYD's historic triumph in 2023, when it surpassed Tesla in global sales of electric vehicles for the first time.

This case demonstrates that BYD's resilience to market disruptions is not a coincidence. It is a direct result of the company's well-established supply chain, which has been in place for a long time, even before the onset of crises. BYD has proven that strategic integration of production and supplier diversity not only provides short-term advantages but also fosters systemic resilience, which translates into leadership in the global market.

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Қазақстан Республикасында әйелдер кәсіпкерлігін қолдау: дамыту механизмдері мен трансформациялау

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Аннотация

Қазақстан Республикасында әйелдер кәсіпкерлігін дамыту қазіргі экономикалық саясаттың басым бағыттарының бірі болып табылады. Әйелдердің кәсіпкерлік қызметке белсенді қатысуы экономиканың әртараптануына, жаңа жұмыс орындарының құрылуына және әлеуметтік тұрақтылықтың қамтамасыз етілуіне ықпал етеді. Осы мақалада әйелдер кәсіпкерлігінің қазіргі жағдайы, оның даму тенденциялары, институционалдық және қаржылық қолдау механизмдері, сондай-ақ трансформациялау бағыттары кешенді түрде қарастырылады.

Зерттеу нәтижелері Қазақстанда әйелдер шағын және орта бизнес субъектілерінің шамамен 45–48%-ын құрайтынын көрсетеді. Сонымен қатар, әйелдер кәсіпкерлігінің жалпы ішкі өнімге қосқан үлесі 14–15% шамасында бағаланады. Дегенмен, қаржыландыруға қолжетімділіктің шектеулі болуы, гендерлік стереотиптердің сақталуы және цифрлық дағдылардың жеткіліксіздігі әйелдер кәсіпкерлігінің дамуын тежейтін негізгі факторлар болып табылады.

Мақалада ұсынылған трансформациялық модель әйелдер кәсіпкерлігін қолдаудың кешенді жүйесін қалыптастыруға бағытталған.

Түйін сөздер: әйелдер кәсіпкерлігі, гендерлік саясат, ШОБ, Қазақстан экономикасы, қаржыландыру, цифрландыру, трансформация

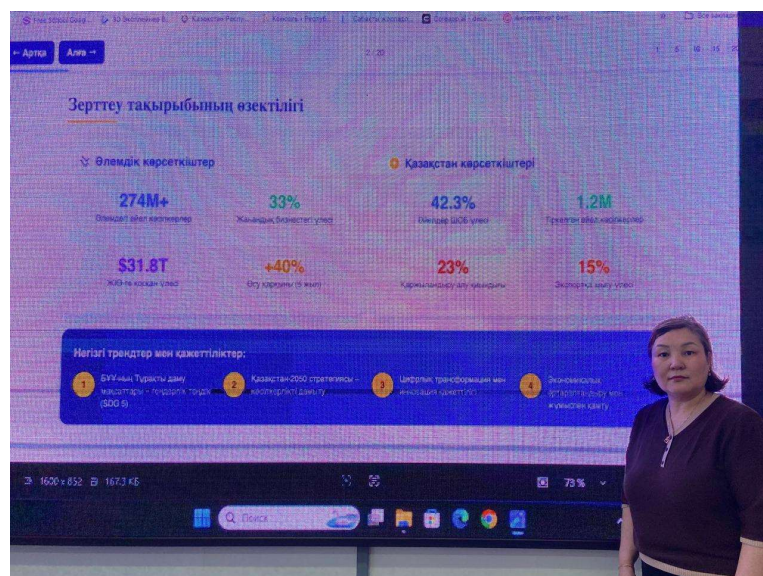
Қазіргі жаһандану жағдайында әйелдер кәсіпкерлігі экономикалық өсудің маңызды драйверлерінің бірі ретінде қарастырылады. Әлемдік тәжірибе көрсеткендей, әйелдердің кәсіпкерлік белсенділігі ұлттық экономиканың тұрақты дамуына, инновациялардың енгізілуіне және еңбек нарығының тиімді жұмыс істеуіне ықпал етеді. Әйелдердің экономикалық қатысу деңгейінің артуы гендерлік теңдікті қамтамасыз етумен қатар, әлеуметтік әділеттілікті нығайтады.

Қазақстан Республикасында әйелдер кәсіпкерлігі соңғы жылдары қарқынды дамып келеді. Елдегі экономикалық реформалар, шағын және орта бизнесті қолдауға бағытталған мемлекеттік бағдарламалар, сондай-ақ цифрлық технологиялардың дамуы әйелдердің кәсіпкерлік қызметке тартылуына оң әсерін тигізді.



Қазақстан Республикасы Үкіметінің деректеріне сәйкес, әйелдер елдегі барлық кәсіпкерлердің шамамен 45%-ын құрайды:

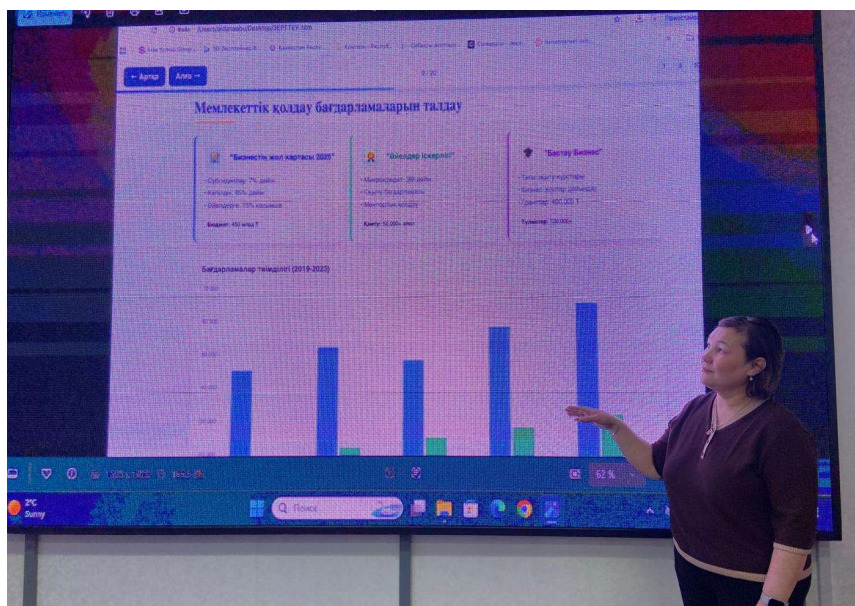
<https://primeminister.kz/en/news/women-business-owners-account-for-45-of-all-business-owners-in-kazakhstan-23342>



Сонымен қатар, әйелдер кәсіпкерлігі елдің жалпы ішкі өнімінің маңызды бөлігін қамтамасыз етеді: https://qazinform.com/news/how-does-women-entrepreneurship-develop-in-kazakhstan_a3905364

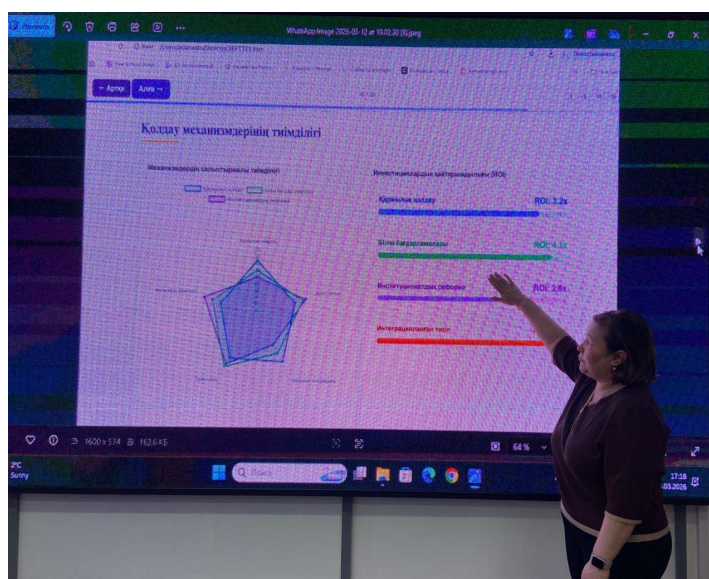
Бұл көрсеткіштер әйелдер кәсіпкерлігінің экономикалық жүйедегі рөлінің жоғары екенін көрсетеді.

Алайда, әйелдер кәсіпкерлігінің дамуы бірқатар жүйелік кедергілерге тап болып отыр. Олардың қатарына қаржылық ресурстарға қолжетімділіктің шектеулі болуы, бизнес жүргізу тәжірибесінің жеткіліксіздігі, гендерлік стереотиптердің сақталуы және цифрлық дағдылардың төмен деңгейі жатады.



Осыған байланысты, әйелдер кәсіпкерлігін қолдау механизмдерін жетілдіру және олардың трансформациялық дамуын қамтамасыз ету ғылыми зерттеудің өзекті бағыты болып табылады.

Әйелдер кәсіпкерлігін зерттеу әлемдік ғылыми әдебиеттерде кеңінен қарастырылған. Ғалымдар бұл құбылысты экономикалық, әлеуметтік және институционалдық тұрғыдан талдайды.



OECD ұйымының зерттеулеріне сәйкес, әйелдер кәсіпкерлігінің дамуына әсер ететін негізгі факторлар қаржыландыруға қолжетімділік, білім беру деңгейі және институционалдық қолдау болып табылады:

https://www.oecd.org/en/publications/bridging-the-finance-gap-for-women-entrepreneurs_75b52972-en.html

Зерттеулер көрсеткендей, әйелдер кәсіпкерлер қаржылық ресурстарға қол жеткізуде ерлерге қарағанда жиі қиындықтарға тап болады. Бұл олардың бизнесін кеңейту мүмкіндіктерін шектейді.

Орталық Азия елдеріндегі зерттеулер әйелдер кәсіпкерлігінің дамуына мәдени және әлеуметтік факторлардың да әсер ететінін көрсетеді:
<https://www.researchgate.net/publication/376030520>

Қазақстан жағдайында жүргізілген зерттеулер әйелдердің кәсіпкерлік қызметке қатысуына гендерлік стереотиптердің әсер ететінін және олардың қаржылық ресурстарға қолжетімділігінің шектеулі екенін дәлелдейді:

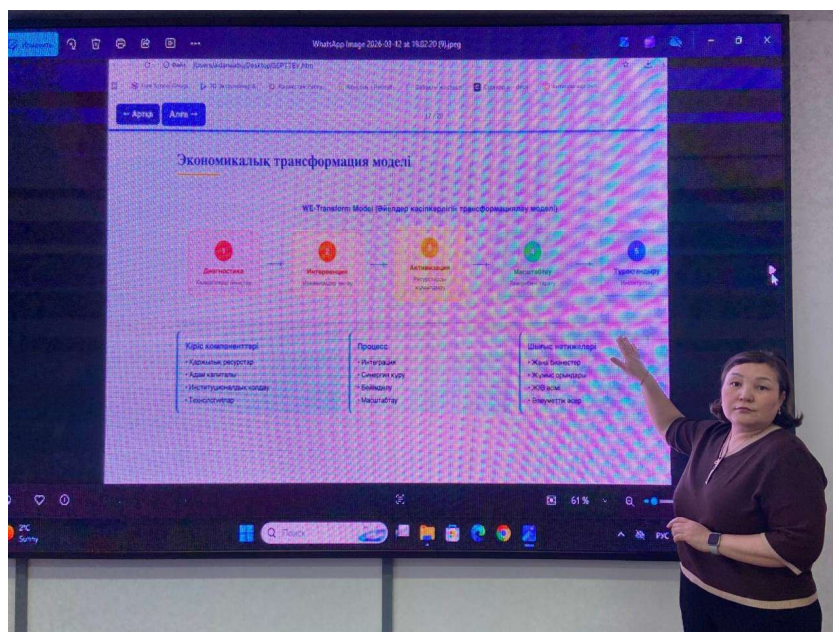
https://longreads.cabar.asia/femalebusinesskz_eng

Сонымен қатар, халықаралық тәжірибе көрсеткендей, әйелдер кәсіпкерлігін дамыту үшін кешенді қолдау жүйесін қалыптастыру қажет.

Бұл зерттеу кешенді әдіснамалық тәсілге негізделген. Зерттеу барысында сандық және сапалық әдістер үйлестіріліп қолданылды.

Зерттеудің негізгі әдістері:

- статистикалық талдау – әйелдер кәсіпкерлігінің даму динамикасын анықтау үшін
- салыстырмалы талдау – халықаралық тәжірибені зерттеу үшін
- институционалдық талдау – мемлекеттік саясатты бағалау үшін
- контент-анализ – ғылыми әдебиеттерді талдау үшін



Зерттеу дереккөздері ретінде ҚР Ұлттық статистика бюросының мәліметтері, халықаралық ұйымдардың есептері (OECD, UN Women), сондай-ақ ғылыми мақалалар пайдаланылды.

Зерттеу дизайны әйелдер кәсіпкерлігінің даму деңгейін кешенді бағалауға бағытталған.

Зерттеу нәтижелері Қазақстандағы әйелдер кәсіпкерлігінің қарқынды дамып келе жатқанын көрсетті.

Әйелдер шағын және орта бизнес субъектілерінің шамамен 48%-ын басқарады:

<https://www.trend.az/business/4015181.html>

Бұл көрсеткіш әйелдердің экономикалық белсенділігінің жоғары екенін дәлелдейді.

Сонымен қатар, әйелдер кәсіпкерлігі негізінен қызмет көрсету, білім беру және сауда салаларында шоғырланған. Бұл салалар әйелдер үшін қолжетімді және бастапқы капиталды көп қажет етпейді.

Алайда, зерттеу барысында әйелдер кәсіпкерлігінің дамуына кедергі келтіретін бірқатар факторлар анықталды.

Біріншіден, қаржыландыруға қолжетімділіктің шектеулі болуы. Венчурлық қаржыландырудағы әйелдердің үлесі небәрі 7%-ды құрайды:

<https://astanatimes.com/2024/03/letting-women-lead-bridging-finance-gap-for-women-led-businesses/>

Екіншіден, цифрлық дағдылардың жеткіліксіздігі. Қазіргі цифрлық экономика жағдайында бұл фактор бизнес жүргізу тиімділігіне айтарлықтай әсер етеді.

Үшіншіден, гендерлік стереотиптердің сақталуы. Бұл әйелдердің кәсіпкерлік қызметке қатысуына кері әсер етеді.

Алынған нәтижелер әйелдер кәсіпкерлігін дамыту үшін кешенді тәсіл қажет екенін көрсетеді.

Қазіргі қолдау механизмдері жеткіліксіз және оларды жетілдіру қажет.

Біріншіден, қаржылық қолдау жүйесін дамыту қажет. Әйелдерге арналған арнайы қаржылық бағдарламаларды енгізу олардың бизнесін дамытуға мүмкіндік береді.

Екіншіден, білім беру жүйесін жетілдіру қажет. Кәсіпкерлік дағдыларды дамытуға бағытталған бағдарламалар әйелдердің бәсекеге қабілеттілігін арттырады.

Үшіншіден, цифрлық технологияларды енгізу маңызды. Цифрлық экономика жағдайында әйелдердің цифрлық дағдыларын дамыту олардың бизнесін жаңа деңгейге көтереді.

Сонымен қатар, халықаралық тәжірибе көрсеткендей, әйелдер кәсіпкерлігін дамыту үшін мемлекеттік саясат пен жеке сектордың өзара әрекеттестігі маңызды рөл атқарады.

Бұл зерттеуде әйелдер кәсіпкерлігін дамытуға арналған көпдеңгейлі трансформациялық модель ұсынылады.

Модель төрт негізгі деңгейден тұрады:

1. Базалық деңгей

- құқықтық реттеу
- қаржылық қолдау

2. Даму деңгейі

- білім беру бағдарламалары
- кәсіпкерлік оқыту

3. Инновация деңгейі

- цифрландыру
- стартап экожүйе

4. Тұрақты даму деңгейі

- ESG
- SDGs интеграциясы

Бұл модель әйелдер кәсіпкерлігін жүйелі түрде дамытуға мүмкіндік береді.

Қазақстан Республикасында әйелдер кәсіпкерлігі экономиканың маңызды сегментіне айналды. Оның дамуы экономикалық өсімге, жұмыспен қамтуға және әлеуметтік тұрақтылыққа оң әсер етеді.

Алайда, әйелдер кәсіпкерлігінің толық әлеуетін іске асыру үшін бірқатар мәселелерді шешу қажет. Олардың ішінде қаржыландыруға қолжетімділікті арттыру, цифрлық дағдыларды дамыту және институционалдық қолдауды күшейту маңызды.

Ұсынылған трансформациялық модель әйелдер кәсіпкерлігін дамытуға бағытталған тиімді құрал болып табылады және оны практикалық деңгейде енгізу Қазақстан экономикасының тұрақты дамуына ықпал етеді.

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Estimating the dynamic relationship between Energy Use, Economic activity and CO₂ emission by using a Panel ARDL Model on a few SADC country member

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Abstract

This paper investigates both the dynamic and long-run relationships between CO₂ emissions, energy consumption, and economic activity using a Panel Autoregressive Distributed Lag (ARDL) model, in which CO₂ emissions are specified as the dependent variable. To examine the direction of causality among the variables, the Granger causality test is employed. The estimation is conducted using the Pooled Mean Group (PMG) method on panel data comprising eight Southern African Development Community (SADC) countries over the period 1990–2014.

The empirical results reveal a significant causal relationship running from economic activity and energy consumption to CO₂ emissions during the study period. The long-run coefficients are all statistically significant at the 1% level, indicating the existence of a cointegration relationship among the variables. Since the variables are expressed in logarithmic form, the estimated coefficients can be interpreted as elasticities. Notably, CO₂ emissions respond negatively to GDP, suggesting environmental deterioration associated with increased economic activity.

Furthermore, the error correction term is negative and statistically significant, as expected. The estimated speed of adjustment indicates that approximately 73% of any deviation from the long-run equilibrium is corrected within each period.

keywords : *cointegration, Panel ARDL, economic activity*

A. Introduction

Recently, global warming and environmental issue has been a growing interest because of its negative and considerable effect both on economic activity and social welfare. Not only developed countries but also developing ones are facing climatic-based problems but at different scale. Moreover, the way they dealt with such a problem depends on the instruments they are holding.

The principal hypothesis over which climate change debate rely on alluded to the Environmental Kuznets Curve (EKC) assumption. In this respect, one certainly knows that economic activity is obviously in correlation with pollution and degradation of the environment, but to a certain level this is not yet verified when referencing to this (EKC) Hypothesis (Kaika & Zervas, 2013).

Hence, according to Alagidede et al., two school of thoughts emerged by showing a real contradiction: the one stating that the sustainability of environment needs to slow down economic growth and those that confirm technological breakthrough and application of new techniques could mitigate the undesirable effect of economic activity. However, the empirical findings resulting from these two assumptions depends on the country or the group of country, the period of study and the methodology adopted. So, as pointed out by Amjath-Babu et al., the tendency towards the environmental and social degradation, due to economic activity, is evident. In fact, the more economic activity that uses energy, the greater the environmental degradation. Economic growth definitely requires lots of resources but at the cost of the environment destruction where impacts are nonreversible.

As one knows, among of the principal greenhouse gases contributor of climate change is the CO_2 because it is mainly considered as the products of economic activities potentially driving to growth and development (Mladenovic et al., ' 2016). Nevertheless, there are other greenhouse gases that can have an impact on economic growth, namely methane (NH_4)² and nitrous (NO_2) (Yusuf et al., 2020). In this study, evidence showed the impact of other greenhouse gases on economic growth and energy consumption. Concerning the nexus between CO_2 emission, Energy consumption and economic growth, extent literature has contributed to many different points of view. With this in mind, Energy consumption got a great attention due to its impact on environment and economic growth and, also, because of its characteristics as renewable or non-renewable resources. Carbon Dioxide (CO_2) emission, recognized as the major pollutant among the greenhouse gases emission, has also a direct linkage with energy use and economic activity (Acaravci & Ozturk, 2010).

The objective of this paper is twofold: the first one is to investigate the dynamic relationship of CO_2 emission level on energy use and economic activity both at long and short term and, the second one, to estimate a long run relationship through a Panel Autoregressive Distributed Lag Model. To test the direction of the relationship, Granger non-causality test will be performed. Then the main contribution of this survey is the use of such techniques on a few groups of African countries in the assessment of the effect of Energy use and growth on CO_2 emission. This paper is organized as followed: in section 2, a brief literature will be introduced and followed by the methodology and results in section 3. Finally, section 4 will end up with a concluding remark.

B. Literature review

By considering a panel data of 30 regions in China, the studies of dynamic relationship between economic growth, CO_2 emission and energy consumption through the spatial Durbin model displays a significant and positive impact of economic growth on carbon dioxide emissions. Inversely, the investigation found that the reduction of carbon dioxide emission does not have a significant impact on economic growth (Zou & Zhang, 2020).). In their paper, they found a unidirectional linkage running from GDP to energy consumption and from energy consumption to carbon emission as well, in the long run. In the same way as Zou and Zhang, Empirical investigation exhibit an insignificant impact of both carbon emission and energy consumption on economic activity (Zhang & Cheng, 2009). Moreover, regarding the effect of GDP (proxy of economic activity) on Carbon emission, Balibey (2015), Zaman et al. (2016), Chaabouni and Saidi (2017), Saidi and Hammami (2015) found a positive result according to empirical evidence. Hence, as the economy activity extends, the environmental effects deteriorate. Contrarily to that, GDP has a decreasing effect on carbon emission Kasman and Duman (2015). Concerning the effect of energy consumption on carbon emission, a positive impact has been pointed out by Arouri et al. (2012), Salahuddin and Gow (2014), Masih and Masih (1998), Pao and Tsai (2010), Saidi and Hammami (2015), Vickers (2017), Apergis and Payne (2010). Results shows that non-renewable, industrial

and residential energy consumption has a positive correlation with on CO₂ emission while renewable has not (Salari et al., 2021). By using static and dynamic model, they found a long run relationship among various types of energy consumption and CO₂ emissions at the state level. Their work provides a reflexion of the empirical validation of the well-known Environmental Kuznets Curve hypothesis (EKC). So, in the perspective of African context, some evidence has been found out on the support of this EKC hypothesis. For example, those of Sulemana et al. (2016) and Osabuohien et al. (2014) use Panel data to state the relevance of EKC on African Economy but only for oil-producing country. however, this was not confirmed according to Effiong and Oisaozoje (2016). Similarly, Ogundipe et al. (2014), Yaduma et al. (2015), Adu and Denkyirah (2019), examined the EKC for African Economies but discovered no proof for its presence. In terms of causality, the empirical studies on Turkey about the relationship among Energy Consumption, Economic growth and carbon emissions, Soytas and Sari (2009) showed evidence that carbon emissions cause energy consumption, but the contrary did not. According to the empirical evidence of Alam et al. (2012) on the existence of the dynamic causality between energy consumption, electricity consumption, carbon emissions and economic growth, a unidirectional causality exists from energy consumption to economic growth both in long and short run. They also found a unidirectional causality that goes from energy consumption to CO₂ emission in the short run and CO₂ emissions to economic growth in both short and long run.

In the same manner, studies carried out on Italy by Magazzino (2016) over the period 1970–2006 showed that there is not a cointegration relationship between CO₂ emissions, energy consumption and economic activity. However, according to Toda and Yamamoto approach (Toda & Yamamoto, 1995), Granger non-causality test exhibit a bidirectional causality between CO₂ emissions and economic growth as well as between CO₂ emissions and energy consumption

C. Methodology

In this paper, one use the Non-Granger-causality approach to test the direction of the causality relationship (Seth, 2007). Then, proceed to the panel unit root test following the Pedroni (1995) approach in order to check the order of the integration of each variable. Before running our Panel ARDL model, we need to make sure that these order of integration does not exceed 2 (Pesaran et al., 2001), so either I(0) or I(1). According to Pesaran et al.'s paper, Panel ARDL can combine such order of integration difference. For the estimation method, we run a pooled mean group model in order to consider a homogenous model.

1. Data description

Our sample consists of a balanced panel data in which one have 8 cross-section composing by the Southern African Development Community (SADC) countries, namely Angola, Botswana, Mozambique, Namibia, Tanzania, Zimbabwe, Congo Democratic Republic and Mauritius over the period 1990- 2014. All data are provided by the World Bank Open database (WDI,2023) along with its description:

Table 1: data description

Variables	description	Description
CO2 in Kt	Carbon Dioxide emission	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.
GDP in US\$	Gross Domestic Product	GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products
EU kt of oil equivalent	Energy use	Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport

Sources: World Bank, World Development Indicators

2. Granger Causality test

Applied on a Panel data, this test is an extension of “Granger Causality” method developed by Granger (1969), where instead of testing causal relationship among two variables, it enables the assessment of causal interactions among multiple variables in a system. The null hypothesis for each pair of variables is that no variable “Granger-causes” the other to end up with a conclusion of the direction and strength of the causality Table 2: Pairwise Granger Causality Tests.

Null Hypothesis	Obs	F-Statistic	Prob.
<i>logeu</i> does not Granger Cause <i>loggdp</i>	181	0.57	0.57
<i>loggdp</i> does not Granger Cause <i>logeu</i>	182	2.78*	0.07
<i>logCO2</i> does not Granger Cause <i>loggdp</i>		0.22	0.80
<i>loggdp</i> does not Granger Cause <i>logCO2</i>		6.19***	0.00
<i>logCO2</i> does not Granger Cause <i>logeu</i>	182	3.21*	0.04
<i>logeu</i> does not Granger Cause <i>logCO2</i>		2.89*	0.06

NB: the sign *, **, *** denote significance at 10%, 5% and 1%.

The test shows that the null hypothesis of the “does not Granger-cause” (Seth, 2007) is rejected for both *loggdp* to *logeu* at 10% and for *logCO2* to *logeu* at 5%. Likewise, we observe the rejection of this Null hypothesis for *loggdp* to *logCO2* and *logeu* to *logCO2* respectively at 1% and 10%. However, it is accepted for *logeu* to *loggdp* and for *logCO2* to *loggdp*.

3. Unit Root Test

The unit root test according to Levin et al. (2002) is carried out to determine the order of integration of our individual series. For the common unit root test, Breitung (2002) approach is used, knowing that the null hypothesis is the non-stationarity. One selects Akaike Information Criterion (AIC) as an information criterion.

Table 3: Unit Root test
Newey-West automatic bandwidth selection and Bartlett kernel

	Method	Stat in level	stat in first diff
Null: Unit root			
<i>loggdp</i>	Levin, Lin & Chu t*	-1.24	-7.14***
<i>logeu</i>	Breitung t-stat	-0.94	-6.58***
	Levin, Lin & Chu t*	-1.05	-6.98***
<i>logCO2</i>	Breitung t-stat	1.25	-3.45***
	Levin, Lin & Chu t*	0.62	-3.45***
	Breitung t-stat	0.30	-2.19***

The null hypothesis of unit root test (Pesaran et al., 2001) is rejected if the computed statistical value is greater than the critical value. Our findings show that all variables are stationary at 1% but at first difference. Even if all variables are $I(1)$ but not mix ($I(0)$ and $I(1)$), Panel ARDL techniques can be used to estimate our Model.

4. Panel cointegration test

As a dependant variable, one has CO_2 emission whereas the independent variables are energy consumption and the economic activity which is a proxy GDP. To test a long run relationship, we will use the Panel cointegration test method as suggested by Pedroni (1995), the null hypothesis being the “no cointegration”.

Table 4: Panel cointegration test

Null Hypothesis: No cointegration

Alternative hypothesis: common AR coeffs. (within-dimension)

Panel v-Statistic	Statistic	Prob.
	4.95	0.00
Panel rho-Statistic	-1.10	0.14
Panel PP-Statistic	-3.56	0.00
Panel ADF-Statistic	-4.31	0.00

Alternative hypothesis: individual AR coeffs. (Between-dimension)

Group rho-Statistic	Statistic	Prob.
	0.47	0.68
Group PP-Statistic	-2.94	0.00
Group ADF-Statistic	-3.81	0.00

In the first block of the test where the alternative hypothesis is “common AR coefficient”, 3 out of the 4 statistics reject the null hypothesis of “no cointegration” at 1% while 2 out of 3 is observed in the “individual AR coeffs” block and still at 1%.

According to the rule of democracy, there is likely a long run relationship between *logCO2*, *logeu* and *loggdp*

5. The Panel ARDL Model

In this survey, we are using a Panel ARDL model to estimate the long run equilibrium relationship, taking CO_2 as the dependent variable and Energy use and Economic activity as the regressors. The above causality test showed a two pairwise causality, but for our purpose we will

only retain that of energy use and economic activity to CO₂ emission. Then, even if our variables are all I(1), we may use such model as the presence of variables with an order of integration of either only I(0) or only I(1), or both I(0) and I(1) is allowed (Pesaran et al., 2001). In terms of estimation method, this study will use the Pooled Mean Group (PMG) Method developed by Pesaran et al. (1999). In their paper, Pesaran, Shin, and Smith introduced the PMG method as an econometric technique for the estimation of a dynamic panel data models by capturing the heterogeneity across individual units. Hence, the long run coefficient is the same (homogeneity) across the group (cross-section) while the short run and cointegrating coefficient vary. Anyway, their contribution to the economic research was a point of departure for the extension of the empirical cointegration analysis.

Table 5: ARDL(4,4,4)

Variable	Coefficient	Std. Error
Long Run Equation/dep var: $\log CO_{2,t}$		
$\log eu_t$	1.85***	0.12
$\log gdp_t$	-0.23***	0.03
Short Run Equation / dep var : $\Delta \log CO_{2,t}$		
ect_{t-1}	-0.73**	0.26
$\Delta \log CO_{2,t-1}$	0.33*	0.19
$\Delta \log CO_{2,t-2}$	0.20	0.19
$\Delta \log CO_{2,t-3}$	0.28	0.18
$\Delta \log eu_t$	0.29	0.77
$\Delta \log eu_{t-1}$	-0.85**	0.39
$\Delta \log eu_{t-2}$	0.06	0.46
$\Delta \log eu_{t-3}$	-1.11**	0.42
$\Delta \log gdp_t$	0.06	0.06
$\Delta \log gdp_{t-1}$	0.06	0.07
$\Delta \log gdp_{t-2}$	-0.03**	0.07
$\Delta \log gdp_{t-3}$	-0.01	0.07
α	0.69**	0.24
$trend$	0.02**	0.01

NB: the sign *, **, *** denote significance at 10%, 5% and 1%.

This table displays the estimates of the Pooled Mean Group (PMG) method, both at short and long run. According to the AIC criterion, an ARDL(4,4,4) model has been selected. In the long run, PMG estimates of the coefficients of GDP were found to have a significant and negative effect (1%) on CO₂ emission, showing that an increase of economic activity is associated with a decrease of CO₂ emission. However, energy consumption impacts positively and significantly at 1% on CO₂ emission. The more the energy consumption, the greater the environmental degradation. In short run, the constant and trend terms are significant at 5%. The error correction term is also significant and negative (-0.73) as expected.

D. Concluding remarks

In this paper, we use a Panel ARDL Model according to the work of Pesaran et al. (2001) even if the unit root test displays that all variables are non-stationary in level but stationary in first difference (I(1)). In addition, the results of the panel cointegration test following Pedroni (1995) exhibit the presence of a long run relationship between CO₂ emission, energy use and Economic activity. However, although the Granger causality test to support CO₂ emission as a dependent variable, Energy use also may be a potential candidate to play such a role. Our findings show a

significant (at 1%) and negative impact (-0.23) of GDP on CO_2 emission in the long run, as stated by Kasman and Duman (2015). Then a 1% increase in GDP is associated with a 0.23% fall in CO_2 emission expressed in kt. Such results imply that the SADC countries is likely to be on the second part of the U inverted-shape curve where an additional economic activity decrease the environmental degradation (negative slope). This negative coefficient (-0.23) witnesses such statement, which is in line with Salari et al. (2021) results, but in contradiction with Ogundipe et al. (2014), Yaduma et al. (2015) and Adu and Denkyirah (2019). This decrease of CO_2 emission may be attributed not only to the intensity of the technology utilization that is less harmful to the environment but also to the abatement effort. This group of country has jumped over the early stage of the environmental destruction of an economic growth. We also found a significant positive impact (at 1%) of energy consumption on CO_2 like Salari et al. (2021). Yet, one record a 1.85% rise of CO_2 emission when energy use increase by 1%. To mitigate such effect, the government has to use more renewable energy and substitute, for instance, energy originating from fossil fuel to like biofuel, solar power and wind energy. However, like this latter, our findings do not coincide with that of Zou and Zhang (2020) affirming a positive impact of GDP on CO_2 . In terms of long run equilibrium, empirical findings show that the error correction is negative and significant at 5%, that is -0.73. This represents the speed of adjustment, meaning that the deviation from long run equilibrium path will be corrected at a level of 73% in each period, that is to say a full recovery at 1.37 period. We may conclude the SADC country has high performance to absorb shock stemming from the departures of the carbon dioxide to its equilibrium level. In fact, we can say variables are cointegrated and the regressor - energy use and GDP - are jointly Granger cause CO_2 emission in the long run. At the end but not the least, the Pooled mean group estimation method clearly demonstrates heterogeneity within the SADC country in the short run, while homogeneity is observed in the long run.

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INVENTORY MANAGEMENT: CONCEPTS, MODELS AND STRATEGIES

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Introduction

Inventory management is one of the key functions of logistics and strategic enterprise management, which has a direct impact on the efficiency of production and commercial processes. In a modern economy characterized by high demand dynamics, globalized markets, and accelerated technological transformation, ensuring optimal inventory levels is becoming a critical factor in companies' competitiveness.

The scientific novelty of this study lies in the comprehensive consideration of concepts, models and strategies of inventory management with an emphasis on their adaptation to modern economic conditions, including the integration of digital technologies and forecasting tools.

The theoretical significance of the work lies in the systematization of existing approaches to inventory management, the analysis of their advantages and disadvantages, as well as in the development of proposals for optimizing models. This makes it possible to expand the scientific understanding of the mechanisms for forming an effective inventory management policy.

The practical significance of the research lies in the possibility of applying the results obtained to increase the efficiency of enterprises, reduce costs, minimize the risks of shortage or excess of inventory, as well as improve the quality of customer service.

The purpose of the study is to identify and analyze modern concepts, models, and strategies for inventory management, determine their applicability in various economic conditions, and offer recommendations for improving the effectiveness of inventory management policies at enterprises. The relevance of the topic is due to the growing demands on the efficiency, flexibility and accuracy of inventory management in conditions of unstable demand and global competition.

Within the framework of this work, the following tasks were solved to achieve this goal:

The review of existing concepts and models of inventory management is carried out.

Strategic approaches to inventory formation are analyzed.

Key factors affecting the effectiveness of inventory management have been identified.

Examples of practical application of various models and strategies of inventory management are considered.

Recommendations for optimizing inventory management processes have been developed.

The research allowed us to systematize theoretical knowledge in the field of inventory management and propose practical solutions aimed at improving the efficiency of modern enterprises.

Literature review

Inventory management is an important aspect of the effective functioning of modern enterprises, having a direct impact on the optimization of production and logistics processes. In the Cheng study, inventory management is considered as a multifaceted phenomenon related to

operational research and strategic decision-making. The author emphasizes that effective inventory management requires the integration of theory and practice, including forecasting and analysis methods, which minimizes planning errors and increases the competitiveness of the company [1].

In turn, Fathy, AbdelGaber, and Mostafa analyze various inventory control strategies such as ABC, XYZ, EOQ, and ROP. They note that each of these strategies has its limitations, depending on the structure of the product range and fluctuations in demand. The authors conclude that the optimal inventory management strategy should be combined and flexible to take into account the specifics of a particular business [2].

In his article, Cao examines inventory management issues in multi-level perishable goods supply chains. The author emphasizes that the key factor of efficiency is the interaction of all participants in the supply chain, the use of demand forecasting and consideration of the specifics of goods. This reduces the risks of shortage and excess reserves [3].

The article by Maitra examines the modeling of inventory management under stochastic, unpredictable demand. The author uses methods of Monte Carlo simulation and Bayesian optimization. Dynamic models with continuous inventory revision provide higher profits and planning accuracy compared to periodic methods [4].

An analysis of modern research shows that effective inventory management requires an integrated approach that includes mathematical and logistical models, as well as strategic planning tools. The main trends include the integration of forecasting methods, flexible management strategies, the interaction of supply chain participants, and the use of dynamic models to account for demand uncertainty. These conclusions emphasize the need for a combination of theory and practice to optimize the reserve policy of enterprises in modern economic conditions.

Research methodology

As part of the study, a method was applied that consisted in analyzing practical cases and statistical data obtained from enterprises operating in the field of production and trade.

The materials included information on stocks, purchase volumes, shelf life, as well as performance indicators for inventory management of specific companies.

The use of this method made it possible to evaluate how various inventory management models and strategies are implemented in practice, to determine their impact on cost reduction, deficit prevention and optimization of material flows.

The analysis of cases and statistical data made it possible to identify real problems and successful practices, which made it possible to compare theoretical models with practical results and draw conclusions about the applicability of specific inventory management strategies in modern economic conditions.

Results and discussion

Inventory management in the world's leading companies is a comprehensive process that optimizes inventory, reduces costs, improves customer service, and speeds up order fulfillment. Effective inventory management systems include demand forecasting, the use of the Just-in-Time model, automated distribution, ABC analysis, and the use of integrated digital technologies (table 1).

Table 1 – The company's inventory management practices and their results.

Company	Industry	Inventory Management Practice	Key Metric	Result
Amazon	E-commerce	Integration of AI, robotics, and predictive algorithms to optimize fulfillment centers	Reduction of stockouts	Decreased out-of-stock items by ≈35%, reduced revenue loss by ≈\$2 billion/year
Toyota	Automotive	Uses Just-in-Time model for timely delivery of materials	Reduction of excess inventory	Significant reduction of warehouse inventory, lower costs, increased production flexibility
Walmart	Retail	Automated inventory monitoring and replenishment systems	Improved product availability	Maintains optimal stock levels, ensures timely replenishment, improves cash flow
Nestlé	Food Industry	ABC analysis to classify inventory by importance	Reduction of inventory management costs	Reduced costs by ≈25%, increased operational efficiency by ~20%
JD.com	E-commerce	Integrated assortment planning and inventory distribution (data-driven)	Local demand fulfillment	Increased local order fulfillment by ~0.54–1.05% through optimized inventory allocation

The source was compiled by the author.

An analysis of the actual inventory management practices of the world's leading companies shows that the integration of modern technologies and artificial intelligence, for example, from Amazon, allows inventory management in real time. This reduces the shortage of goods and increases the level of customer service [5].

The use of Toyota's Just-in-Time model helps reduce excess inventory and increase production flexibility. This is especially important for enterprises with dynamic demand and complex production processes [6].

Automation and inventory monitoring used by Walmart ensure that the optimal level of goods in warehouses is maintained. This reduces costs and improves the financial stability of the company [7].

The use of ABC analysis and inventory differentiation in Nestlé allows you to direct resources to the most valuable product groups. This reduces costs and increases the effectiveness of management decisions. In addition, integrated allocation and scheduling algorithms similar to those used in JD.com contribute to more efficient execution of local orders and optimization of inventory distribution across the network, which is especially valuable for distributed logistics platforms.

The analysis of these cases allows us to conclude that effective inventory management is a complex of digital, analytical and strategic approaches, including demand forecasting, automation of processes and classification of goods. These approaches can reduce excess inventory and storage costs, enhance customer service, and provide flexibility in the face of market uncertainty.

Thus, inventory management is not only a logistical function, but also a strategic tool for increasing a company's competitiveness in modern business conditions.

Conclusion

The main thesis of this study is that effective inventory management is a strategic tool that has a direct impact on the competitiveness of an enterprise.

An analysis of modern concepts, models, and strategies for inventory management has shown that the integration of digital technologies, demand forecasting, process automation, and inventory classification and differentiation can not only reduce excess inventory and associated costs, but also improve customer service and provide flexibility in the face of market uncertainty.

For the research topic, this means that inventory management goes beyond the logistical function and becomes a key factor in the strategic development of companies, especially in conditions of high dynamics and competition in the economy.

The results of the study show that the use of flexible and adaptive inventory management models in combination with analytical and digital tools helps optimize material flows and increase the efficiency of enterprises.

In the future, this research will focus on integrating artificial intelligence, big data, and automated planning systems to create more accurate forecasts, reduce operational risks, and develop intelligent inventory management systems in real time.

Thus, the study not only confirms the relevance and importance of inventory management for modern business, but also opens up prospects for the introduction of innovative solutions that will increase the strategic stability and competitiveness of companies in the future.

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АКТУАЛЬНЫЕ НАПРАВЛЕНИЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ УПРАВЛЕНИЯ ПРЕДПРИЯТИЕМ

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В современных условиях рыночной экономики в основе успешной деятельности любой компании в нашей стране лежит повышение эффективности управления. Существует множество способов повышения эффективности менеджмента. Их объектами могут выступать руководитель, личные и профессиональные качества управленцев, элементы управленческой деятельности. Работа в области повышения эффективности управления организации может быть начата с любого ее элемента, т. е. с наиболее актуального для предприятия. Необходимо только учитывать взаимосвязь элементов системы управления друг с другом. Пути повышения эффективности управления предприятия условно делят на восемь групп:

- 1) совершенствование структуры управления предприятия направлено на ее максимальное упрощение, децентрализацию, распределение и определение полномочий сотрудников управления с учетом требований к квалификации и личным качествам;
- 2) разработка стратегии развития предприятия на основе анализа ее деятельности, оценки сильных и слабых сторон, выработка философии, концепции, миссии и политики предприятия;
- 3) разработка и внедрение информационной системы компании, которая должна обеспечивать эффективную коммуникационную связь между сотрудниками и подразделениями;
- 4) внедрение системы принятия и разработки управленческих решений, правил и процедур управления, систем стимулирования и мотивации;
- 5) разработка и внедрение системы непрерывного повышения квалификации сотрудников на основе обучения, переподготовки, развития инициативы, творчества;
- 6) разработка алгоритма, регламента или систем подбора, обучения, аттестации или оценки руководящего персонала компании, планирование карьеры руководителей, применение стиля руководства, адекватного внутренним и внешним факторам, воздействующим на организацию;
- 7) применение наиболее эффективных методов подбора персонала, его оценки, формирование работоспособного, совместимого состава работников, создание максимально благоприятного социально-психологического климата;
- 8) работа по созданию культуры организации, выработке совместных ценностей, признаваемых и одобряемых сотрудниками.

Рассмотрим более детально некоторые из путей повышения эффективности

менеджмента. В современных условиях для эффективности управленческого процесса необходимо, чтобы любой менеджер не только имел глубокие и разносторонние знания, но и отличался оперативностью и деловитостью, обладал чувством нового, постоянно проявлял инициативу.

На развитие эффективности трудовой деятельности работника, в том числе и в сфере управления, можно воздействовать. Важным стимулом квалификационного роста руководящего работника и развития его инициативы является систематическое продвижение по службе. Менеджер должен твердо знать, что вопрос о его продвижении подлежит обязательному периодическому рассмотрению. Однако это продвижение будет зависеть во многом от того, как он повышает деловую квалификацию, насколько активен в работе.

Продвижение менеджеров может осуществляться в форме:

- перемещения в рамках той же должностной категории и размеров заработной платы, но с расширением выполняемых функций;
- повышения заработной платы без повышения в должности;
- продвижения его по ступеням должностной лестницы.

Росту эффективности менеджмента способствует система повышения квалификации с отрывом и без отрыва от производства. Повышение квалификации направлено на совершенствование и углубление знаний, умений и навыков работника в конкретном виде деятельности.

Стимулирующая роль в повышении эффективности труда руководящих работников выполняет их периодическая аттестация. Основная цель аттестации – выявить, на что способен тот или иной работник, чего он заслуживает. Но при этом проявляется и ее вторая сторона. Чувство ответственности перед предстоящей аттестацией побуждает менеджера к более полному использованию своих способностей, к достижению лучших результатов в труде.

Одним из наиболее важных путей повышения эффективности управления считается активная поддержка новаторства в организации. Создание и поддержка атмосферы творческого поиска – прямая задача руководителей компании.

Факторами, поддерживающими новаторство, считают: предоставление необходимой свободы при разработке новшества, обеспечение новаторов необходимыми ресурсами и оборудованием, поддержка со стороны высшего руководства; ведение дискуссий по обмену идеями; поддержание эффективных коммуникаций с коллегами, другими подразделениями, вузами и внешними научными организациями; углубление взаимопонимания между работниками.

Одним из наиболее действенных путей повышения эффективности управления является мотивация. Мотивация – стимулирование к деятельности, процесс побуждения себя и других к работе, воздействие на поведение человека для достижения личных, коллективных и общественных целей.

Существует определенная система мотивов к труду. В нее входят мотивы: содержательности труда, его общественной полезности; статусные, связанные с общественным признанием плодотворности трудовой деятельности; получения материальных благ; ориентированные на определенную интенсивность работы.

Одной из основных задач менеджера для повышения эффективности управления является определение мотивов деятельности каждого сотрудника и согласование этих мотивов с целями предприятия.

Важную роль в обеспечении эффективного управления играет делегирование, которое означает поручение выполнения определенных задач подчиненным. Преимуществами делегирования являются:

- высвобождение руководителя для выполнения наиболее важных работ;
- расширение объема выполняемых организацией заданий;
- развитие у подчиненных инициативности, умения и навыков, профессиональной компетенции;
- расширение уровня принятия решений.

Менеджеру следует помнить о том, что делегирование заданий и полномочий не освобождает его от ответственности. Делегирование – это не способ уйти от ответственности, а форма разделения управленческого труда, позволяющая повысить его эффективность.

Эффективность или неэффективность управления в значительной степени определяется организационной структурой менеджмента на предприятии. От правильного выбора организационной структуры зависят быстрота и экономичность принятия решений, результативность выполнения поставленных руководством задач, а, следовательно, и общая эффективность менеджмента на предприятии.

Для повышения эффективности управления предприятию можно внести какие-либо изменения в существующую структуру управления или полностью изменить ее.

Организационная структура формируется, как правило, с учетом специфики и масштабов деятельности предприятия, количества рынков сбыта, размера управленческого штата и т. д. Процесс деления организации на отдельные блоки, связанные с организационным выделением и обособлением групп сложных работ, называют департаментизацией.

В настоящее время существуют следующие виды организационных структур управления:

1) линейная департаментизация – характеризуется простотой, одномерностью связей (только вертикальные связи) и возможностью самоуправления; эффективна при выполнении организацией однотипных работ без дифференциации специалистов (например, в низовых производственных звеньях, семейном и малом бизнесе и т. д.);

2) функциональная департаментизация – процесс деления организации на отдельные элементы, каждый из которых имеет свою четко определенную задачу и обязанности. целесообразно использовать в организациях, выпускающих ограниченную номенклатуру продукции, действующих в стабильных внешних условиях;

3) департаментизация по продукту (продуктовая) – выделяются блоки, связанные с производством и реализацией какого-либо продукта;

4) по такому же принципу строится департаментизация по потребителю и по рынку: группирование работ осуществляется вокруг конечного потребителя или в отношении географических и отраслевых рынков производства и продаж (территориальные отделения крупной компании);

5) традиционная департаментизация основана на комбинации линейной и функциональной департаментизации; основой этой структуры являются линейные подразделения, осуществляющие в организации основную работу и обслуживающие их специализированные функциональные подразделения;

6) дивизиональная организация – сочетание централизованного планирования наверху и децентрализованной деятельности производственных отделений; эффективна в условиях много продуктового производства или многонациональных компаниях с большой территориальной разобщенностью;

7) матричная организация комбинация функционального и продуктового подходов, где функциональная часть матрицы ответственна за обеспечение работы спецификациями, техническим руководством и т. д., а продуктовая – отвечает за

выполнение работы, управление и оценку результатов, выполнение рабочих операций, достижение целей.

Матричные организации создаются в том случае если стратегия создана с упором на получение высоких результатов по большому количеству проектов в области высоких технологий.

Выбор оптимальной организационной структуры в значительной степени повышает эффективность менеджмента и результаты деятельности организации в целом.

В деятельности предприятия существенную роль играют информационные системы, обеспечивающие коммуникационные связи между сотрудниками и подразделениями.

При формировании эффективной информационной системы организации используют различные способы, но необходимо понимать, что только системный подход к информационному обмену позволит гибко управлять работой компании.

Существует большое разнообразие путей и методов стимулирования роста эффективности менеджмента, каждый из которых ориентирован на какую-то определенную область деятельности организации.

Повысить эффективность управления можно также, используя различные методы воздействия непосредственно на менеджера: повышение квалификации, дополнительное образование, рост мотивации и т.д.

Каждое предприятие самостоятельно решает вопрос о выборе методов стимулирования роста эффективности менеджмента, в зависимости от особенности деятельности и особенностей существующей системы управления.

Таким образом, каждому руководителю необходимо сознавать, что наибольшая эффективность управленческой деятельности достигается в том случае, если используются различные методы в комплексе, при этом они ориентированы на цели и стратегии развития организации.

Осознание проблемы состоит в установлении факта ее существования по результатам контроля деятельности или исследования рыночных возможностей. Проблема, достигая определенной остроты, трансформируется в мотив для деятельности организации и ее менеджеров. Структурировать проблему позволяет процесс построения дерева проблем. Дерево проблем приведено на рисунке.



По результатам работы по выявлению проблемы, перед предприятием была поставлена цель – увеличить объемы сбыта продукции и снизить текучесть кадров, а также снизить дебиторскую задолженность.

В целом, основная проблема снижения эффективности продаж связана с перестройкой стратегии фирмы. В рамках решения данной проблемы можно выделить несколько направлений ее решения. С одной стороны, это изменение методологического подхода к организации службы маркетинга на предприятии. А с другой стороны, это изменение влияния человеческого фактора на решение проблемы.

Анализ внутренней и внешней среды – это очень важный для выработки стратегии организации и очень сложный процесс, требующий внимательного отслеживания происходящих в среде процессов, оценки факторов и установления связи между факторами и теми сильными и слабыми сторонами организации, а также возможностями и угрозами, которые заключены во внешней среде. Очевидно, что, не зная, что происходит во внешнем окружении и не развивая свои внутренние компетентные стороны, компания очень скоро начнет терять конкурентное преимущество, а затем может просто исчезнуть с рынка.

Во-первых, в ходе проведения анализа динамики, состава и структуры источников формирования капитала и его размещения было определено, что предприятие как на начало, так и на конец периода имело «легкую» структуру активов; при этом структура оборотных активов сформирована за счет денежных средств, запасов и дебиторской задолженности. Кроме того, возросла стоимость как внеоборотных, так и оборотных активов. Что касается пассивов, то на конец периода изменилось соотношение собственных и заемных средств, в пользу первых (их доля в структуре пассивов увеличилась), что свидетельствует о благоприятной тенденции. Краткосрочные обязательства в абсолютном изменении уменьшились, за счет снижения отдельных статей, таких как задолженность перед персоналом организации и прочими кредиторами. Однако значительно растет задолженность по налогам и сборам, что свидетельствует о невыполнении предприятием своих обязательств перед государством.

Во-вторых, в ходе проведения анализа ликвидности баланса было выявлено, что на начало периода у условного предприятия наблюдался недостаток наиболее ликвидных активов для покрытия наиболее срочных обязательств, что свидетельствует о текущей ликвидности баланса. Но уже к концу периода ликвидность стала абсолютной в результате увеличения денежной наличности на счетах предприятия.

Далее был проведен анализ финансовой устойчивости, который выявил, что на начало периода предприятие находилось в кризисном состоянии, однако к концу периода за счет увеличения собственных средств, вызванного ростом нераспределенной прибыли, устойчивость стала абсолютной.

Резюмируя вышесказанное, можно сделать вывод, что единственно правильным вариантом поведения компании для достижения эффективного долгосрочного функционирования и успешного развития уделяется повышенное внимание осуществлению анализа внешнего и внутреннего окружения. Это подразумевает проведение комплексного анализа, который может быть проведен с использованием вышеперечисленных методик, который дает достаточно ясное и объективное представление о конкурентном положении компании. Только при этом условии можно рассчитывать на эффективность принимаемых стратегических и оперативных управленческих решений.

МАРКЕТИНГОВЫЕ ИССЛЕДОВАНИЯ КАК ИНСТРУМЕНТ СТРАТЕГИЧЕСКОГО РАЗВИТИЯ ХОЛДИНГА BI GROUP: ЦИФРОВЫЕ ТРЕНДЫ И ПСИХОЛОГИЧЕСКИЕ АСПЕКТЫ

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В настоящем отчете анализируются современные методы маркетинговых исследований, применяемые крупнейшим строительным холдингом Казахстана — BI Group. Рассматривается трансформация подходов к изучению потребительского поведения под влиянием цифровизации, нейронаук и актуальных трендов 2025–2026 годов. Особое внимание уделено влиянию киберпсихологии, инструментам анализа больших данных (Big Data) и стратегическому формированию «экономики доверия» в секторе девелопмента.

Ключевые слова: маркетинговые исследования, девелопмент, BI Group, цифровая психология, нейромаркетинг, потребительское поведение, тренды 2026 года.

Введение

Рынок недвижимости Казахстана в период 2025–2026 годов определяется высокими показателями рыночной неопределенности и интенсивной конкурентной борьбой за лояльность конечного потребителя. В этих условиях традиционные, ретроспективные методы сбора и анализа данных демонстрируют снижение своей прогностической ценности. Современный покупатель жилья функционирует преимущественно в сложной цифровой среде, где процесс принятия критически важного решения о приобретении недвижимости трансформируется в многоэтапный когнитивный процесс, который подвержен постоянному влиянию алгоритмов искусственного интеллекта и новых медиаплатформ. Лидеры рынка, в частности холдинг BI Group, вынуждены переводить маркетинговые исследования из плоскости констатации фактов в область предиктивной аналитики, базирующейся на глубоком и научно обоснованном понимании цифровой психологии клиента.

Основная цель данного аналитического обзора состоит в исследовании и систематизации современных инструментов маркетинговых исследований и рыночной аналитики, эффективно применяемых холдингом BI Group, а также в их сопоставлении с актуальными научными трендами в области прикладного маркетинга и киберпсихологии, определяющими стратегическое развитие компании.

1. Методология маркетинговых исследований в BI Group

Стратегическая маркетинговая деятельность BI Group основывается на применении «гибридного» подхода к исследованиям. Данный подход представляет собой синергию проверенных временем классических полевых методик и высокотехнологичного анализа цифрового следа, оставляемого клиентами в экосистеме холдинга.

1.1. Система сквозного мониторинга лояльности (NPS)

Холдингом внедрена комплексная, сквозная система измерения индекса потребительской лояльности (Net Promoter Score), которая охватывает все ключевые точки

соприкосновения клиента с продуктом и сервисом. Замеры NPS проводятся на непрерывной основе: начиная с момента предварительного бронирования объекта, проходя через этап приемки готовой квартиры и завершая фазой эксплуатации через аффилированную сервисную компанию. Такой проактивный мониторинг позволяет оперативно идентифицировать возникающие «болевые точки» в пользовательском пути и осуществлять незамедлительную корректировку предлагаемого продукта в соответствии с динамично меняющимися рыночными запросами.

1.2. Предиктивная аналитика на основе Big Data

BI Group активно капитализирует массивы данных, генерируемые внутренней цифровой экосистемой. Аналитическая работа выходит за рамки сбора стандартных демографических показателей и фокусируется на детализированном изучении поведенческих паттернов клиентов. Это включает мониторинг частоты использования корпоративного мобильного приложения, глубины интереса к различным финансовым инструментам, а также скорости реакции потенциальных покупателей на анонсы и изменения в условиях ипотечных программ. Предиктивные модели, построенные на этих данных, позволяют прогнозировать будущий спрос и планировать продуктовые линейки с высокой степенью точности.

1.3. Цифровая этнография и UX-исследования

Фундаментальной частью аналитической работы является глубокое изучение пользовательского опыта (UX) в рамках фирменного мобильного приложения BIG App. Маркетинговые подразделения проводят систематическое исследование когнитивной нагрузки, которую испытывает потенциальный покупатель в процессе взаимодействия с цифровыми продуктами. Установлено, что высокая степень простоты интерфейса и лаконичность, ясность UX-копирайтинга прямо коррелируют с уровнем доверия клиента и способствуют существенному снижению уровня тревожности, традиционно сопутствующего совершению дорогостоящих покупок в сфере недвижимости.

2. Киберпсихология и поведение потребителя в цифровой среде

Перенос процессов продаж и коммуникации в онлайн-пространство требует обязательного учета специфических психических феноменов, детально описанных в современной поведенческой науке и киберпсихологии.

2.1. Эффект онлайн-растормаживания (Disinhibition Effect)

Исследования в области киберпсихологии убедительно демонстрируют, что цифровая среда способствует более импульсивному и менее сдержанному поведению пользователей. BI Group принимает этот фактор во внимание при проектировании и оптимизации систем онлайн-продаж, в частности, платформы BI Click. Маркетинговые изыскания показывают, что возможность быстрой транзакции, например, покупки «в один клик», должна быть строго уравновешена внедрением психологически значимых «точек доверия». К таким элементам относятся прямые видео-трансляции со строительных объектов и предоставление полных, верифицированных цифровых паспортов объектов недвижимости.

2.2. Формирование «экономики доверия»

Аналитические прогнозы, актуальные для 2026 года, однозначно указывают на то, что абсолютным доминирующим активом на рынке становится доверие потребителя. Стандартные, обезличенные рекламные сообщения утрачивают свою эффективность. BI Group активно использует результаты своих исследований для стратегической гуманизации бренда. Вместо продвижения абстрактных корпоративных лозунгов, компания сосредоточила усилия на развитии личных брендов своих ключевых экспертов — ведущих инженеров и архитекторов. Полученные эмпирические данные надежно подтверждают вывод: уровень доверия, который реципиент склонен оказывать конкретному, узнаваемому

специалисту в цифровом поле, превышает доверие к абстрактному корпоративному логотипу на величину, достигающую 50 процентов.

3. Аналитический разбор экосистемы: BIG App и BI Click

Практическая реализация и валидация результатов маркетинговых исследований холдинга сосредоточены в его ключевых технологических продуктах. Эти продукты выполняют двойную функцию: они являются не только прямыми каналами продаж, но и высокоэффективными инструментами непрерывного сбора данных.

Мобильное приложение **BIG App** выступает в роли основного инструмента цифровой этнографии. Благодаря анализу поисковых запросов и поведенческих паттернов, фиксируемых внутри приложения жителями, компания получает детализированную картину востребованности той или иной сопутствующей инфраструктуры, включая коворкинги, специализированные детские площадки и общественные зоны отдыха, в привязке к конкретным жилым локациям.

Система онлайн-покупки **BI Click** предоставляет уникальную возможность для проведения многовариантного А/В-тестирования различных предложений и конфигураций сделок в режиме, максимально приближенном к реальному времени. Маркетинговые аналитики способны отслеживать точные моменты и этапы воронки продаж, на которых клиент демонстрирует повышенные колебания или сомнения, что позволяет немедленно инициировать корректирующие мероприятия с использованием инструментов нейромаркетинга и поведенческой экономики.

Для наглядности, ниже представлена таблица, обобщающая фундаментальную трансформацию методологических подходов в период с 2020 по 2026 год.

Таблица 1. Трансформация подходов к исследованиям (2020 vs 2026)

Параметр	Традиционный подход (2020 г.)	Подход BI Group (2026 г.)
Основной источник данных	Опросы, фокус-группы	Big Data, AI-аналитика
Объект исследования	Потребность в «квадратных метрах»	Образ жизни и психология
Коммуникация	Официально-деловая	Живой голос, экспертность
Метод оценки	Объем продаж за период	NPS и жизненный цикл (LTV)

4. Тренды 2026 года: ИИ-поиск и иммерсивный маркетинг

Аналитические результаты, полученные BI Group, однозначно свидетельствуют о смене парадигмы поиска потребителем релевантной информации на рынке.

4.1. Поиск без клика (Zero-click search)

К 2026 году прогнозируется, что доля пользователей, получающих информационные ответы напрямую от генеративных нейросетей без необходимости переходить на внешние веб-ресурсы, может достигать 60%. В ответ на этот тренд, компания переориентирует усилия по контент-маркетингу на концепцию **Native SEO**. Это подразумевает создание эталонных, глубоко экспертных материалов, которые алгоритмы искусственного интеллекта будут

использовать в качестве верифицированных и авторитетных источников для предоставления ответов потенциальным покупателям.

4.2. Иммерсивный маркетинг

Активное внедрение иммерсивных технологий, таких как высокодетализированные VR-туры и инструменты дополненной реальности, на самых ранних стадиях проектирования объектов позволяет проводить так называемые «пре-исследования» спроса. Холдинг осуществляет точные замеры эмоционального отклика и поведенческой реакции покупателей во время их виртуального посещения еще не построенного объекта. Эти данные критически важны для оптимизации планировочных решений и конфигурации общественных пространств до начала фактического строительства, минимизируя риски, связанные с несоответствием продукта рыночным ожиданиям.

5. Этика нейромаркетинга и управление репутацией (SERM)

Масштабное применение психологических триггеров и методов воздействия в маркетинге несет за собой неотъемлемую этическую ответственность. В рамках стратегии управления репутацией (SERM), BI Group фокусируется на поддержании максимально прозрачного и открытого информационного поля. Исследования убедительно показывают: в условиях доминирующего «цифрового скептицизма» любая попытка манипуляции, особенно та, что ассоциируется с псевдонаучными течениями (например, привлечение внимания через сомнительные практики, такие как нумерология Сюцай), вызывает резкое и консолидированное отторжение у рационально мыслящей аудитории. Вследствие этого, BI Group делает стратегическую ставку на научную обоснованность принимаемых решений и полную прозрачность всех бизнес-процессов.

Заключение

Резюмируя проведенный анализ, можно констатировать, что достижение и поддержание лидерских позиций холдинга BI Group напрямую обусловлено глубинной интеграцией современных маркетинговых исследований в его цифровую экосистему. Переход от традиционного анализа спроса к комплексному исследованию киберпсихологии потребителя, активное внедрение предиктивной AI-аналитики, а также стратегическое развитие личных брендов внутренних экспертов, позволяют холдингу устанавливать новые отраслевые стандарты. Сегодня результаты маркетинговых исследований служат не просто аналитическим инструментом, но и прочным фундаментом для создания не просто объектов недвижимости, а целостной, высококачественной и человекоцентричной городской среды.

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СТРАТЕГИЧЕСКИЕ ПРЕИМУЩЕСТВА BI GROUP НА РЫНКЕ ЖИЛИЩНОГО СТРОИТЕЛЬСТВА ГОРОДА КАРАГАНДЫ: АНАЛИЗ И РЕКОМЕНДАЦИИ

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Аннотация. Статья посвящена анализу стратегических преимуществ BI Group на рынке жилищного строительства города Караганды и выявлению факторов, определяющих конкурентные позиции компании в региональной среде. На основе теоретических подходов стратегического менеджмента, а также данных о состоянии рынка недвижимости, структуре спроса и поведении потребителей сформированы ключевые направления стратегического развития девелопера. Исследование демонстрирует, что устойчивость BI Group обеспечивается сочетанием технологических, финансовых и репутационных преимуществ, однако эффективная реализация потенциала требует адаптации продуктовой и ценовой политики к структуре локального спроса. Полученные результаты подтверждают актуальность стратегической трансформации компании в условиях высокой конкуренции и насыщенности рынка.

Ключевые слова: конкурентное преимущество; стратегическое управление; рынок недвижимости Караганды; BI Group; девелоперские компании; потребительский спрос; конкурентная среда; стратегическое развитие.

Введение. Актуальность исследования обусловлена усиливающейся конкуренцией на рынке жилищного строительства Караганды, где рост числа девелоперов, структурный дисбаланс между спросом и предложением и требования покупателей к качеству и доступности жилья формируют необходимость выявления устойчивых стратегических преимуществ компаний. В этих условиях BI Group, являясь одним из крупнейших игроков отрасли, сталкивается с задачей адаптации своей бизнес-модели к специфике регионального рынка, что придает научную и практическую значимость анализу ее конкурентных позиций.

Проблема исследования заключается в недостаточной определенности стратегических механизмов, позволяющих BI Group эффективно укреплять свои позиции в условиях перенасыщенного рынка, ценовой конкуренции и смещенного потребительского спроса. Сложность состоит в необходимости согласования внутренних возможностей компании с динамикой локального спроса и особенностями поведения конкурентов.

Цель исследования состоит в определении стратегических преимуществ BI Group на рынке жилищного строительства Караганды и формировании научно обоснованных рекомендаций, направленных на повышение ее конкурентоспособности в региональном контексте.

Задачи исследования направлены на выявление факторов, формирующих текущее положение компании на рынке, анализ ее внутренних ресурсов и технологических возможностей, оценку конкурентной среды и поведения потребителей, а также разработку направлений стратегического развития, соответствующих структуре и потребностям регионального спроса.

Гипотеза исследования заключается в предположении, что стратегические преимущества BI Group могут быть эффективно реализованы при условии комплексного анализа внутренней среды, точного учета конкурентных факторов и адаптации продуктовой и ценовой стратегии к локальным запросам населения. Реализация данных условий позволит компании укрепить позиции на рынке Караганды и сформировать долгосрочные конкурентные преимущества в условиях высокой рыночной турбулентности.

Литературный обзор. Теория конкурентного преимущества занимает центральное место в стратегическом менеджменте и служит основой долгосрочного успеха организации. Ее развитие связано с работами Майкла Портера, который в 1980-е годы предложил системный подход к анализу рыночных позиций компании. Портер определил конкурентное преимущество как способность создавать ценность, превосходящую ожидания потребителей или издержки конкурентов. Он показал, что устойчивое превосходство формируется через стратегии лидерства по издержкам или дифференциации, которые укрепляют позиции компании в структуре отраслевой конкуренции [1].

Дальнейшее развитие концепции связано с акцентом на внутренних источниках успеха. Ресурсно-ориентированный подход, предложенный Джеймем Барни, рассматривает конкурентное преимущество как результат использования уникальных ресурсов, обладающих ценностью, редкостью и трудновоспроизводимостью. Такая логика позволяет компаниям снижать зависимость от внешних факторов и формировать преимущества за счет технологий, брендов или организационных процессов [3, с.96].

В условиях усложнения рыночной среды значимость приобрел подход динамических способностей, разработанный Дэвидом Тисом. Он объясняет конкурентное превосходство через способность компании адаптироваться, интегрировать и обновлять свои ресурсы. Быстрая реакция на технологические изменения и гибкость организационных структур становятся ключевыми условиями устойчивости [4, с.78].

Характеристики конкурентного преимущества определяют его стратегическую ценность. Устойчивость отражает способность компании сохранять рыночные позиции несмотря на давление конкурентов. Уникальность демонстрирует степень отличия продукта или бизнес-модели от предложений конкурентов и формирует основу для завоевания новых рынков. Воспроизводимость обеспечивает масштабируемость и стабильность, позволяя компании повторять успешные решения в различных контекстах.

В.Я. Кершенбаум указывает, что современные подходы к конкурентному преимуществу подчеркивают необходимость комплексного анализа ресурсов, технологий и организационных возможностей [5, с.67]. Они демонстрируют, что долгосрочный успех достигается не только благодаря уникальности, но и благодаря способности компании поддерживать и развивать свои преимущества в условиях постоянных изменений.

В.Ф. Максимова отмечает, что критерии анализа конкурентных преимуществ опираются на параметры ценности, редкости, трудновоспроизводимости и организационной применимости [6, с.35]. Их сущность сводится к тому, что ресурс компании должен приносить выгоду, быть доступным ограниченному числу конкурентов, труднокопируемым и встроенным в управленческие процессы. Ценность проявляется в способности ресурса повышать эффективность или снижать издержки. Редкость усиливает стратегическую значимость, поскольку ограниченный доступ создает преимущества на рынке. Трудновоспроизводимость формируется за счет патентов, эксклюзивных технологий

или сложных процессов, защищающих компанию от имитации. Организационная применимость отражает способность фирмы использовать свои ресурсы на практике и обеспечивать их максимальную результативность.

Методы анализа конкурентных преимуществ варьируются в зависимости от отрасли и целей стратегического управления. SWOT-анализ используется для выявления внутреннего потенциала компании и оценки внешней среды, однако его интерпретация зависит от субъективных факторов. Более точную оценку обеспечивают VRIO-подходы, позволяющие определить стратегическую значимость ресурсов на основе их ключевых характеристик. Анализ цепочки создания ценности раскрывает процессы, формирующие потребительскую ценность, и помогает оптимизировать производственные и операционные системы. Бенчмаркинг служит инструментом сравнения с лучшими практиками отрасли и позволяет выявлять направления роста и повышения эффективности [7, с.105].

Устойчивость конкурентного преимущества зависит от защищенности ресурсов, барьеров входа и способности компании адаптироваться к изменениям. Патенты, эксклюзивные контракты и редкие ресурсы создают высокую степень защиты от конкурентов. Высокие входные барьеры, характерные для капиталоемких или строго регулируемых отраслей, укрепляют стратегические позиции компаний и ограничивают появление новых игроков. Гибкость и адаптивность дополняют устойчивость, поскольку позволяют быстро реагировать на изменения внешней среды и корректировать бизнес-модели.

Диагностика конкурентных позиций осложняется тем, что многие ключевые факторы носят нематериальный характер. Бренд, организационная культура и клиентская лояльность трудно поддаются количественной оценке, хотя играют решающую роль в стратегическом развитии компании. Анализ таких ресурсов требует применения специализированных методов, основанных на изучении восприятия бренда и его присутствия в информационном пространстве, что создает дополнительные методологические трудности [8, с.95].

В условиях усиливающейся конкуренции и усложнения внешней среды необходимость точной оценки конкурентных позиций компании становится критически важной. Однако комплексная диагностика сталкивается с методологическими ограничениями, связанными с нематериальной природой значительной части стратегических ресурсов. В этом контексте анализ специфики рыночной среды становится необходимым продолжением теоретической дискуссии, поскольку структурные условия определяют рамки, в которых формируются и реализуются конкурентные стратегии. Именно поэтому обращение к особенностям рынка недвижимости Республики Казахстан позволяет представить комплексную картину факторов, влияющих на стратегическое поведение компаний, и дополнить теоретическую модель эмпирическим контекстом.

Рынок недвижимости в Республике Казахстан в последние годы демонстрирует ряд характерных особенностей, обусловленных экономической конъюнктурой, демографическими и законодательными факторами, а также тенденциями спроса и предложения. Цены на новое и вторичное жилье продолжают расти: по данным на октябрь 2025 года средняя стоимость одного квадратного метра нового жилья составила 554 924 тг против значительно более низких значений на регионах, что отражает рост на 23,6 % за год [9].

Рост цен затрагивает не только новостройки, но и вторичный рынок. Индекс цен на «вторичку» за 12 месяцев к октябрю 2025 года достиг 107,6 %, что соответствует росту на 7,6 % по сравнению с годом ранее [10].

Объемы сделок по покупке-продаже жилья показывают нестабильную, но в целом устойчивую динамику. В июле 2025 года по квартирам было зарегистрировано 31 277 сделок, что составляет 78,7 % от общего количества сделок. При этом около 7,4 % из них

пришлись на Карагандинскую область, что свидетельствует о важности регионального рынка [11].

Динамика спроса демонстрирует рост, особенно в многоквартирных домах. В июле 2025 года число сделок по квартирам-многоквартиркам увеличилось по сравнению с июнем на 23 %, что говорит о восстановлении активности на рынке после сезонных колебаний [12].

Рынок новостроек реагирует на изменения регулирования и экономических условий. В 2025 году рост цен на первичное жилье ускорился – по итогам девяти месяцев рост составил порядка 11,4 %, что превышает темпы роста цен на вторичное жилье (9,2 %) [13].

Среди факторов, влияющих на рынок, – инфляция, волатильность курса национальной валюты, ужесточение условий долевого строительства и ожидания повышения НДС, что создает давление на цены и стимулирует рост стоимости жилья. В условиях таких тенденций возрастает интерес к аренде жилья. Стоимость аренды благоустроенного жилья в марте 2025 года составила в среднем 4 515 тг за кв. м, что на 11,6 % больше, чем в аналогичном периоде прошлого года [14].

Тем не менее активность рынка распределяется неравномерно по регионам. В крупнейших городах наблюдается более высокая динамика как цен, так и сделок, тогда как в ряде регионов рост замедляется или цены остаются стабильными.

Таким образом, рынок недвижимости Казахстана в 2024–2025 гг. характеризуется стабильным, хотя и неравномерным ростом цен, оживленным спросом на новостройки, смещением интереса к аренде на фоне роста цен и повышением активности сделок. Эти особенности формируют сложную, но понятную картину, в которой девелоперы и покупатели адаптируют свое поведение под влиянием экономических, законодательных и региональных факторов.

Методология исследования. Методологическая основа исследования включает комплекс аналитических и сравнительных методов, направленных на выявление стратегических факторов и оценку рыночного положения компании. Используются методы сбора и обработки статистических данных о рынке недвижимости Караганды за 2023–2025 годы, анализ финансовой отчетности и корпоративных материалов ВI Group, а также результаты опросов потребителей. Применены инструменты стратегического анализа, включая PESTEL-моделирование, модель пяти сил Майкла Портера, сравнительный анализ структуры предложения и спроса. Такой подход позволил комплексно оценить конкурентные преимущества компании и сформировать обоснованные стратегические рекомендации.

Аналитическая часть. Карагандинская область представляет собой один из ключевых индустриальных и наиболее урбанизированных регионов Казахстана. По данным Бюро национальной статистики, численность населения региона на 1 декабря 2025 года достигла 1131,4 тыс. человек, при этом уровень урбанизации превышает 82,5%. Устойчивый миграционный приток формирует стабильный средне- и долгосрочный спрос на жилую недвижимость.

Экономика региона, базирующаяся на промышленности, энергетике и сервисном секторе, обеспечивает относительную стабильность занятости. В третьем квартале 2025 года среднемесячная заработная плата в области составила 410 314 тенге, что, уступая показателям мегаполисов, формирует предсказуемый платежеспособный спрос, локализованный преимущественно в сегментах «комфорт» и «комфорт+». Таким образом, рынок недвижимости Караганды характеризуется не неограниченным, но устойчивым и прогнозируемым спросом, что определяет перспективность планомерного освоения территории вместо агрессивного масштабирования.

Дополнительным фактором инвестиционной привлекательности выступает рост экономической активности в регионе: объем инвестиций в 2024 году достиг 1,4 трлн тенге,

а реализация 13 крупных инвестиционных проектов усиливает мультипликативный эффект и стимулирует спрос на жилье.

Рынок первичной недвижимости Караганды в ноябре 2023 года демонстрировал устойчивую активность девелоперов и выраженную диверсификацию жилищных проектов по классам. В городе функционировало 22 компании-застройщика, что формировало конкурентную среду и обеспечивало насыщенность предложения. К 2025 году число участников увеличилось до 23, что подтверждает дальнейшее развитие рынка и его привлекательность для девелоперского сектора.

Ценовая динамика отражала постепенный рост стоимости жилья. В ноябре 2023 года средняя цена достигала 324 000 тенге за квадратный метр, тогда как в марте 2025 года показатель увеличился до 398 000 тенге. Структура предложения была сосредоточена преимущественно в сегменте комфорт-класса, доля которого составляла 55 % в 2023 году и возросла до 59 % в 2025 году. Средняя стоимость квадратного метра в этом сегменте снизилась с 310 000 до 295 000 тенге, что свидетельствует о стремлении девелоперов удерживать доступность жилья при росте объемов строительства.

Бизнес-класс занимал второе место по распространенности. Его доля увеличилась с 32 % в 2023 году до 37 % в 2025 году, при этом ценовой уровень существенно вырос – с 324 000 до 493 000 тенге за квадратный метр. Эта динамика подтверждает смещение спроса части покупателей в сторону более качественного и функционального жилья, а также повышение инвестиционной привлекательности проектов бизнес-категории.

Сегмент стандартного жилья демонстрировал противоположную тенденцию. Его доля сократилась с 8 % до 4 % за рассматриваемый период, несмотря на умеренный рост стоимости с 272 000 до 287 000 тенге за квадратный метр. Снижение интереса к этому сегменту отражает изменения в предпочтениях населения, которое ориентируется на более комфортные потребительские характеристики и развитую инфраструктуру жилых комплексов.

Обеспеченность жильем на одного проживающего показана на рисунке 1.

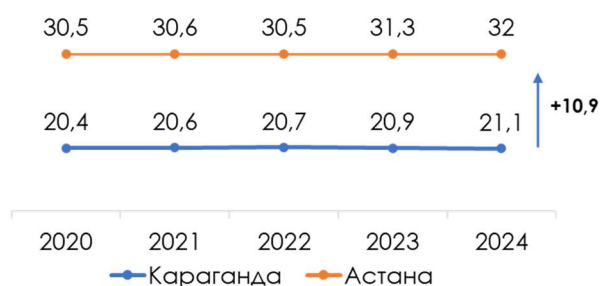


Рисунок 1 – Обеспеченность жильем на одного проживающего, м²

Примечание – составлено авторами на основе данных исследования BI Group

Анализ обеспеченности жильем на одного жителя в Астане и Караганде за период 2020–2024 годов демонстрирует устойчивую положительную динамику. В Астане показатель увеличился с 30,5 м² в 2020 году до 32 м² в 2024 году, что отражает наиболее высокий уровень обеспеченности за весь рассматриваемый период. В Караганде рост был менее выраженным: обеспеченность увеличилась с 20,4 м² до 21,1 м². Совокупный прирост за пять лет составил 10,9 м², что подчеркивает более быстрые темпы развития жилищного фонда в Астане.

Компания BI Group – крупнейший застройщик в Казахстане планирует полноценно войти на рынок г. Караганды. В 2025 году компания повысила уровень надежности для

клиентов, увеличив гарантийный срок на новые жилые проекты до пяти лет - такой шаг стал заметным прецедентом на рынке, и сопровождается внедрением цифровых мониторинговых систем и AI-решений, обещая более высокие строительные стандарты и качество обслуживания. Кроме того, BI Development Ltd. выпустил первый интегрированный отчет за 2024 год, построенный по международным стандартам ESG-отчетности (GRI, SASB, Integrated Reporting Framework), что подчеркивает стремление к прозрачности и устойчивому развитию.

PESTEL-анализ BI Group показан в таблице 1.

Таблица 1 – PESTEL-анализ BI Group на рынке г. Караганды

№	Фактор	Описание
1	2	3
1	Политический	Государственные программы поддержки жилищного строительства в Казахстане стимулируют спрос на новое жилье. Региональные инициативы направлены на развитие инфраструктуры Караганды, что повышает привлекательность новых жилых комплексов.
2	Экономический	Средняя цена на первичном рынке выросла с 303 тыс. тг/м² (январь 2023) до 368 тыс. тг/м² (декабрь 2024), что отражает 21% роста за период. BI Group удерживает премиальный сегмент с ценой 438 тыс. тг/м² в ноябре 2024 года, что на 74 тыс. тг/м² выше среднего по первичке. При этом вторичный рынок показывает стагнацию: 382 тыс. тг/м² (январь 2023) против 381 тыс. тг/м² (ноябрь 2024). Деятельность компании регулируется требованиями к ипотечному кредитованию, которое остается основным способом покупки: 52% респондентов выбирают ипотеку, 28% - рассрочку, лишь 18% готовы к полной оплате. Неустойчивое макроэкономическое положение в стране, высокая ключевая ставка, инфляционные процессы и волатильность тенге создают риски снижения платежеспособного спроса и удорожания строительных материалов.
3	Социальный	Среди опрошенных респондентов 87% покупают жилье для личного проживания, лишь 9% - для инвестиций. Большинство ориентировано на стандарт-класс (48%), бизнес- и премиум-классы выбирают по 6%. Основной запрос – квартиры 2–3 комнаты (78%), новые квартиры от застройщика предпочитают 30% респондентов.
4	Технологический	BI Group внедряет цифровые сервисы и инновации, однако по опросу только 3% респондентов указали интерес к IT- и онлайн-решениям при выборе жилья, что отражает низкий спрос на технологические новшества со стороны покупателей.
5	Правовой	Деятельность регулируется национальными строительными нормами и стандартами. Ключевое влияние оказывает Закон РК «О долевом участии в жилищном строительстве», который устанавливает жесткие требования к финансовой прозрачности застройщиков (обязательное использование специальных банковских счетов и безналичных расчетов, ст. 20) и предоставляет такие инструменты, как гарантия Единого оператора (ст. 8). Для BI Group, как для крупного и финансово устойчивого игрока, соответствие данному закону является конкурентным преимуществом, однако сам регуляторный режим создает угрозу в виде возможного ухода с рынка нестабильных застройщиков, что может подорвать общее доверие к отрасли.
6	Экологический	Растущий интерес к энергоэффективности и благоустройству жилых комплексов, однако в опросе жители уделяют больше внимания цене, качеству и инфраструктуре. Это создает потенциал для позиционирования BI Group через экологичность и современные стандарты застройки.
Примечание – составлено авторами на основе данных исследования BI Group		

PESTEL-анализ деятельности BI Group на рынке Караганды показывает, что стратегическое развитие компании определяется совокупным воздействием экономических, социальных и технологических факторов. Рост стоимости первичного жилья

с 303 тыс. тг/м² в 2023 году до 368 тыс. тг/м² в конце 2024 года отражает устойчивый потенциал рынка, тогда как стабильность цен на вторичном сегменте около 381–382 тыс. тг/м² подтверждает перераспределение спроса в пользу новостроек. Позиционирование BI Group в премиальном сегменте с уровнем 438 тыс. тг/м² обеспечивает высокую маржинальность, но ограничивает доступность продукта для массового потребителя, что становится значимым фактором, учитывая ориентацию 48 % покупателей на стандарт-класс. Структура спроса формируется преимущественно потребителями, приобретающими жилье для личного проживания, доля которых достигает 87 %, при низкой инвестиционной активности в 9 %. Финансовое поведение покупателей усиливает зависимость рынка от ипотечных программ, так как 52 % предпочитают кредитные инструменты, и только 18 % готовы оплачивать жилье полностью. Технологические и экологические факторы пока оказывают ограниченное влияние, что подтверждается низким интересом к IT-решениям, однако перспективы развития энергоэффективных технологий могут изменить конкурентную структуру рынка.

Оценка конкурентной структуры рынка по модели пяти сил Портера позволяет выявить интенсивность отраслевого давления и определить устойчивость стратегических позиций компании BI Group в Караганде (таблица 2). Учитывая высокий уровень конкуренции (23 застройщика в 2025 году), дисбаланс спроса и предложения (3 248 предложений против 327 спроса), а также ценовой разрыв между BI Group и среднерыночными показателями (438 тыс. тг/м² против 368 тыс. тг/м²), анализ по портфелям рыночных сил позволяет комплексно оценить угрозы, возможности и экономическую привлекательность сектора для компании.

Таблица 2 – Анализ пяти сил Портера для BI Group на рынке г. Караганды

№	Рыночная сила	Характеристика влияния	Количественные показатели	Оценка силы давления
1	2	3	4	5
1	Конкуренция между действующими игроками	Высокая насыщенность рынка, активность локальных застройщиков, ценовая конкуренция	23 застройщика (2025); предложение – 3 248 квартир; спрос – 327 квартир; цена BI Group – 438 тыс. тг/м ² , конкуренты – 330–368 тыс. тг/м ²	Очень высокая
2	Угроза появления новых игроков	Барьеры входа высокие: капиталоемкость, требования закона о долевом строительстве, необходимость технологических инвестиций	Стоимость проектов – десятки млрд тг; банковские требования по специальным счетам; опыт успешных игроков – >10 проектов	Низкая–средняя
3	Сила поставщиков	BI Group частично нейтрализует влияние за счет вертикальной интеграции BI Group (модульное строительство Modex), но рынок материалов волатилен	Рост стоимости стройматериалов в 2024–2025 гг. на 12–18%; зависимость от импорта отдельных материалов	Средняя
4	Сила покупателей	Покупатели чувствительны к цене, ориентированы на стандарт-класс (48%), высокий уровень сравнения предложений	87% покупают для личного проживания; 52% – ипотека; разрыв по цене между BI Group и рынком – 74 тыс. тг/м ²	Высокая
5	Угроза заменителей	Вторичный рынок стабилен по цене, но уступает по качеству; аренда конкурирует как временная альтернатива	Вторичное жилье – 381 тыс. тг/м ² (стагнация); аренда выросла на 7% в 2024–2025	Средняя
Примечание – составлено авторами на основе данных исследования BI Group				

Проведенный анализ показывает, что BI Group функционирует в условиях очень высокого конкурентного давления, усиленного дисбалансом рынка, где предложение превышает спрос более чем в десять раз, что значительно снижает скорость продаж и повышает ценовую чувствительность покупателей. Главный вызов – агрессивная конкуренция и высокая сила покупателей, обусловленная широким выбором объектов, разницей в стоимости и ориентацией потребителей на стандартный сегмент.

При этом компания имеет стратегические преимущества: наличие собственной производственной базы (ModeX и собственное архитектурное бюро BI Architects, системы

Revit), высокий уровень доверия (91% покупателей учитывают застройщика), сильный бренд (87% узнаваемости), цифровые сервисы и соблюдение строгих требований законодательства, что снижает угрозу новых игроков и повышает устойчивость бизнес-модели.

В отличие от BI Group, конкуренты как игроки локального рынка могут быть ближе к потребителю внутри города по цене и позиционированию, но при этом менее технологичны, не обладают масштабом и инфраструктурой BI Group, а также ограничены в производственных возможностях и управленческом развитии, что делает их более уязвимыми к внешним вызовам и снижает масштабируемость бизнес-модели. BI Group должна не отрицать ценовое преимущество локальных игроков, а компенсировать разницу через преимущества продукта, условия приобретения, высокий сервис и доверие к бренду.

Для укрепления позиций на рынке Караганды BI Group необходимо адаптировать ценовую и продуктовую политику, расширять проекты стандарт-класса, усиливать предложение в сегменте 2–3-комнатных квартир (78% спроса) и выравнять дисбаланс между спросом и собственным предложением. При грамотной стратегической корректировке BI Group обладает потенциалом удержания и расширения доли рынка даже в условиях высокой отраслевой турбулентности.

Анализ внутренней среды BI Group, конкурентной структуры рынка и потребительских предпочтений позволяет выделить набор стратегических преимуществ, обеспечивающих устойчивые позиции компании на рынке г. Караганды. Эти преимущества формируются как за счет технологических и организационных решений (BIM, ModeX, собственные материалы), так и благодаря сильному бренду, финансовой устойчивости и высокой доверенности среди покупателей (91% учитывают застройщика при покупке). Для системного обобщения результатов исследования разработана таблица 3 ключевых стратегических преимуществ, а также таблица стратегических направлений, вытекающих из анализа текущих рыночных условий.

Таблица 3 – Ключевые стратегические преимущества BI Group на рынке Караганды

№	Стратегическое преимущество	Характеристика и подтверждающие данные
1	2	3
1	Технологическое лидерство	Использование BIM-моделирования и завода ModeX сокращает сроки строительства с 16 до 6 месяцев. Высокоточная технология снижает издержки и повышает качество. Архитектурное бюро BI Architects, системы Revit, позволяющая формировать квартирные листы в единой цифровой модели, приложение BIG App как единое цифровое окно для клиентов.
2	Высокая узнаваемость и доверие покупателей	Бренд BI Group имеет узнаваемость 87% в B2C-сегменте; 91% респондентов учитывают застройщика при покупке жилья. Направление BI Product позволяет создавать устойчивое конкурентное преимущество через ценность продукта.
3	Финансовая устойчивость	Чистая прибыль выросла с 14,9 млрд тг (2022) до 75,8 млрд тг (2025); ROE в 2024 году достигала 61,04%.
4	Развитая производственная база	Наличие вертикальной интеграции BI Group (ModeX и собственные производственные решения) обеспечивает контроль себестоимости и стабильность поставок.
5	Цифровая экосистема	BIG App, BI Click, BI Eco system, CRM. AI-мониторинг повышают качество сервиса и снижают операционные ошибки. Активное использование BIM-технологий снижает нагрузку на команды и сокращает срок подготовки проектов с 12 до менее чем 8,5 месяцев.
6	Высокое качество строительства	Качество является для покупателей одним из ключевых критериев (12%), что совпадает с позиционированием BI Group.
7	Премиальное позиционирование и сильный продукт	Средняя цена объектов BI Group составляет 438 тыс. тг/м ² , что выше рынка на 74 тыс. тг/м ² , формируя премиальный сегмент.
8	Участие в государственных программах и соответствие регуляторным требованиям	Закон «О долевом участии» усиливает позиции крупных и прозрачных компаний; BI Group соответствует повышенным требованиям (ст. 20, ст. 8).
Примечание – составлено авторами на основе данных исследования BI Group		

Представленные стратегические преимущества отражают устойчивые позиции BI Group на рынке Караганды и демонстрируют комплексный характер ее конкурентоспособности. Технологическая база, развитая производственная инфраструктура и цифровые решения создают основу для повышения эффективности строительства и качества конечного продукта. Финансовая стабильность и высокая доверительность бренда усиливают рыночные позиции компании и обеспечивают устойчивый спрос в условиях конкурентной среды. Премиальное позиционирование, поддерживаемое соответствием государственным требованиям, формирует долгосрочные преимущества, позволяющие BI

Group сохранять лидерство и адаптироваться к изменениям рынка. Такая структура преимуществ подтверждает стратегическую устойчивость компании и ее потенциал для дальнейшего развития в регионе.

Сейчас компания внедряет единые BIM-требования и стандарты (3D–4D) как обязательное условие для начала строительно-монтажных работ. В будущем планируется осуществление перехода к 5D-6D BIM с внедрением ИИ. Все эти шаги направлены на высокое качество проектирования, которое даст лучшее качество строительства, соответствующее международным стандартам.

На основе проведенного анализа были сформулированы стратегические направления развития компании, которые представлены в таблице 4.

Таблица 4 – Стратегические направления развития BI Group, разработанные на основе анализа

№	Стратегическое направление	Обоснование на основе данных исследования
1	2	3
1	Диверсификация портфеля проектов	Растущий спрос на стандарт-класс: 48% покупателей, при этом его доля в предложении – лишь 4%.
2	Корректировка ценовой политики	Средняя цена BI Group превышает рынок на 74 тыс. тг/м ² , что снижает конверсию спроса (только 2% спроса при 6% предложения).
3	Внедрение «зеленых» технологий в массовый сегмент	Экологичность становится трендом, но пока мало используется конкурентами; позволяет укрепить позиционирование и повысить ценность продукта.
4	Оптимизация цепочки поставок	Собственное производство материалов снижает зависимость от рынка и позволяет адаптировать цены в условиях волатильности.
5	Расширение участия в социальных программах и ипотечных инициативах	52% покупателей предпочитают ипотеку; 28% – рассрочку. Гибкие финансовые инструменты повышают доступность продукта.
6	Развитие продуктовой линейки среднего класса (2–3 комнаты)	78% покупателей выбирают 2–3-комнатные квартиры; BI Group может усилить предложение в этом сегменте.
7	Укрепление маркетинговых коммуникаций на основе репутационных преимуществ	Надежность – главный критерий выбора застройщика для 25% респондентов.
8	Оптимизация продаж и повышение конверсии спроса	При предложении 157 квартир спрос составляет всего 6 единиц; требуется адаптация продукта и коммуникаций.
Примечание – составлено авторами на основе данных исследования BI Group		

Систематизация преимуществ BI Group показывает, что компания обладает прочной технологической, финансовой и организационной базой, позволяющей эффективно конкурировать на рынке г. Караганды. Однако анализ спроса и структуры предложения выявляет необходимость адаптации продуктовой стратегии – прежде всего усиления сегмента стандарт-класса и оптимизации ценовой модели. Реализация представленных стратегических направлений позволит BI Group увеличить рыночную долю, повысить

конверсию продаж и укрепить конкурентные позиции на фоне перенасыщенности рынка и усиления активности других девелоперов.

Заключение и рекомендации. Проведенный анализ показал, что BI Group обладает рядом устойчивых стратегических преимуществ, связанных с технологическим развитием, финансовой стабильностью и высокой репутацией бренда. Эти факторы обеспечивают компании конкурентоспособность на рынке Караганды, несмотря на его насыщенность и ценовую чувствительность покупателей. Результаты исследования подтверждают необходимость адаптации продуктовой и ценовой политики, особенно в сегменте стандарт-класса, который формирует основной потребительский спрос. Реализация предложенных стратегических направлений позволит компании укрепить рыночные позиции и повысить эффективность деятельности в условиях усиливающейся конкуренции.

В целях укрепления позиций BI Group на рынке жилищного строительства г. Караганды рекомендуется реализовать стратегию системного роста с ориентацией на достижение доли рынка 15% к концу 2027 года. Ключевым направлением должно стать не ценовое соперничество с локальными застройщиками, а формирование нового стандарта городской среды через развитие проектов комплексного освоения территории в формате Bigville. Такой подход позволит компании перейти от проектного присутствия к устойчивому долгосрочному лидерству.

Продуктовую стратегию целесообразно сосредоточить в сегментах комфорт и комфорт+, которые соответствуют 48% потенциального спроса. Основной акцент следует сделать на семейные 2- и 3-комнатные квартиры площадью 45–100 м² как на главный драйвер продаж. Доля 2-комнатных квартир может составить 45% общего объема реализации, 3-комнатных – 30%, 4-комнатных – 10%, 1-комнатных – 15%. Дополнительно рекомендуется предусмотреть не менее 10% предложения с чистовой отделкой, поскольку такой формат отвечает запросам около 30% покупателей.

Ценовая политика должна строиться на модели ценностного лидерства. Компании следует сохранять премиальную ценовую планку и обосновывать стоимость качеством продукта, инфраструктурой и сервисом. Рост среднего чека должен обеспечиваться за счет продуктовой дифференциации, опций отделки и усиления потребительской ценности. Доступность жилья необходимо поддерживать через инструменты BI Finance, программы рассрочки и ипотечные механизмы с государственной поддержкой. Это позволит снизить барьер входа без прямого снижения цены и увеличить конверсию в сделку. Долю повторных продаж целесообразно довести до 15% за счет развития BI Club.

Маркетинговую стратегию рекомендуется строить на многоканальной модели продвижения с акцентом на узнаваемость бренда и доверие потребителей. Цифровые каналы должны обеспечивать до 40% всех лидов. Наружная реклама, локальный digital-таргетинг, радио и имиджевые интеграции должны работать на рост узнаваемости бренда до 95% в B2C-сегменте. Коммуникация должна продвигать не отдельный объект, а ценность среды, образ жизни и преимущества комплексной застройки.

В операционной деятельности BI Group важно усилить применение BIM-моделирования, цифрового контроля строительства, автоматизации приемочных процедур и инструментов управления подрядчиками. Это позволит сократить сроки проектирования на 30%, повысить производительность на 25% и снизить строительные дефекты на 40%. Дополнительно следует оптимизировать логистику через принципы Just-in-time, что обеспечит снижение логистических затрат на 15% и расходов на хранение материалов на 20%. В технологическом блоке необходимо развивать ERP-системы, мобильные решения, IoT-мониторинг и цифровые сервисы для клиентов. Это может дать снижение затрат на 12%, рост производительности на 35% и повышение удовлетворенности клиентов на 30%.

Для оценки результативности стратегии BI Group необходимо внедрить систему контроля KPI. Базовыми ориентирами должны стать ежегодный рост выручки на 25%, достижение доли рынка 15%, соблюдение сроков реализации на уровне 98%, ROI маркетинга 150% и снижение дефектов строительства на 40%. Регулярный мониторинг этих показателей обеспечит своевременную корректировку стратегии и укрепит конкурентные позиции компании на рынке Караганды.

Ограничения связаны с использованием данных за ограниченный период и неполной доступностью информации о деятельности конкурентов. Часть выводов основана на опросах покупателей, что предполагает наличие субъективности. Применение теоретических моделей также не позволяет учесть все специфические факторы рынка.

Будущие исследования могут быть направлены на расширение временного горизонта анализа, моделирование динамики спроса и изучение влияния ESG-подходов на конкурентоспособность девелопера. Перспективным является также исследование факторов лояльности покупателей и эффективности внедряемых технологических решений.

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Brand Value and Financial Results: A Comparative Review of Apple and Samsung

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Key words: Brand Value, Brand Equity, Financial Performance, Apple, Samsung, Revenue, Profitability, Market Capitalization, Shareholder Value, Comparative Analysis, Brand Strategy, Technology Industry

Abstract

This study examines the relationship between brand value and financial performance through a comparative review of Apple and Samsung, two leading global technology companies. Brand value, as a critical intangible asset, significantly affects consumer perception, competitive positioning, and overall financial outcomes. Apple and Samsung, despite operating in the same industry, employ distinct branding strategies: Apple emphasizes premium pricing, innovation, and emotional connection with customers, while Samsung focuses on technological leadership, product diversity, and global accessibility. This research aims to analyze how these brand strategies translate into financial results, including revenue, profitability, market capitalization, and shareholder value. Using a combination of secondary data analysis, including annual reports, brand valuation reports, and financial databases, this study explores the correlation between brand strength and financial performance over a ten-year period. The findings are expected to provide valuable insights for academics, brand managers, and investors, demonstrating the strategic importance of brand value in driving sustainable financial success in highly competitive markets.

Introduction

In today's rapidly evolving and highly competitive technology market, brand value has emerged as one of the most important intangible assets for multinational corporations. Strong brand value not only enhances a company's recognition and credibility but also influences consumer behavior, customer loyalty, and purchasing decisions. Companies with well-established brands are often able to charge premium prices, attract repeat customers, and maintain market share even in the face of intense competition. Consequently, understanding the relationship between brand value and financial performance has become essential for business leaders, marketers, and investors seeking sustainable growth and long-term profitability.

Apple and Samsung are two of the most influential global technology brands, each with distinct approaches to building and leveraging brand value. Apple is widely recognized for its premium brand positioning, innovative product design, high-quality standards, and strong emotional connection with its consumers. Its brand strategy focuses on creating a unique ecosystem of devices and services, fostering customer loyalty and brand advocacy. This approach has allowed Apple to maintain a high level of profitability, strong market capitalization, and significant shareholder returns. On the other hand, Samsung has developed a brand based on technological innovation, product diversity, and accessibility to a global consumer base. Samsung offers a wide range of products across multiple price segments, catering to both premium and mid-market

customers. Its branding emphasizes cutting-edge technology, reliability, and extensive distribution channels, which contribute to strong revenue growth and global market presence.

Despite operating in the same industry, Apple and Samsung employ markedly different branding strategies, making them ideal candidates for a comparative analysis of brand value and financial results. Examining these two companies provides insight into how variations in brand positioning, marketing strategies, and consumer perceptions can translate into measurable financial outcomes, including revenue, profitability, market capitalization, and shareholder value. While there is extensive research on brand equity and financial performance in individual firms, studies comparing the direct impact of brand value across two leading competitors in the technology sector are limited.

This research aims to fill this gap by conducting a detailed comparative review of Apple and Samsung. It will explore how brand value influences financial performance, taking into account key dimensions such as brand awareness, perceived quality, brand loyalty, and brand associations. Moreover, the study will analyze the effectiveness of the companies' brand strategies in generating sustainable financial success and competitive advantage. By investigating these dynamics, the research will contribute to a deeper understanding of the strategic role of brand value in the technology sector and provide practical insights for managers, marketers, and investors seeking to optimize brand-related investments.

Ultimately, this study underscores the importance of brand value not merely as a marketing concept but as a strategic asset that drives financial performance and long-term corporate sustainability. By comparing Apple and Samsung, the research highlights the ways in which brand equity can be leveraged to achieve measurable financial results and maintain a competitive edge in a dynamic global market.

Literature Review

Brand value is a critical intangible asset that plays a significant role in determining a company's market performance and long-term profitability. Academic literature defines brand value as the financial worth derived from consumer perceptions, brand loyalty, awareness, and associations that differentiate a company's products or services from competitors. Aaker (1991) conceptualizes brand equity as a multi-dimensional construct, including brand loyalty, brand awareness, perceived quality, brand associations, and other proprietary brand assets. Similarly, Keller (2003) introduces the Customer-Based Brand Equity (CBBE) model, emphasizing that brand knowledge, awareness, and positive associations influence consumer behavior and, ultimately, the firm's financial outcomes. Both models highlight the critical link between strong brand positioning and sustained competitive advantage.

Several studies have explored the relationship between brand value and financial performance. Research indicates that companies with higher brand equity tend to enjoy increased revenue, profitability, market share, and shareholder value (Farquhar, 1989; Srivastava & Shocker, 1991). High brand equity enhances customer loyalty, reduces price sensitivity, and fosters positive word-of-mouth, all of which contribute to a firm's long-term financial success. Furthermore, strong brands often exhibit resilience during economic downturns, as consumers continue to prefer products associated with trust, quality, and positive experiences.

In the context of Apple, numerous studies emphasize the company's strong brand loyalty, premium pricing strategy, and perceived quality as drivers of its financial performance. Apple's brand strategy relies heavily on innovation, product design, and a cohesive ecosystem of hardware, software, and services. This approach has led to consistently high revenue growth, profit margins, and market capitalization (Kapferer, 2012). The emotional connection Apple fosters with its consumers translates into repeat purchases, brand advocacy, and reduced customer churn, all of which have measurable financial impacts.

Samsung, on the other hand, has focused on technological innovation, extensive product diversity, and global accessibility. Studies highlight that Samsung's brand value stems from its ability to offer products across multiple segments, appealing to a wide range of consumers while maintaining quality and technological leadership. Samsung's strong global brand awareness contributes to revenue growth, especially in emerging markets, and enables the company to remain competitive against rivals in both premium and mid-market segments (Cheng & Hou, 2024).

Comparative studies between Apple and Samsung are relatively limited but suggest important distinctions in how brand value translates into financial results. Apple's concentrated focus on premium products and ecosystem integration generates high-profit margins but targets a narrower consumer segment. Samsung's broader approach enables extensive market coverage but can lead to variability in brand loyalty and perceived quality across segments. Understanding these differences is crucial for evaluating how brand strategies impact financial performance in the technology industry.

Recent research also examines the role of brand equity in shaping investor perceptions and market valuation. Studies indicate that companies with strong brand value are often perceived as more stable and profitable, which positively influences stock performance and shareholder confidence (Wang & Jiang, 2019; El Zein et al., 2020). In the case of Apple and Samsung, brand strength contributes not only to direct sales and revenue but also to investor trust and overall corporate valuation, reinforcing the financial significance of brand value as a strategic asset.

Despite extensive literature on brand equity and firm performance, few studies provide a comprehensive comparative analysis of Apple and Samsung, linking specific brand value dimensions to measurable financial outcomes. This gap highlights the need for research that investigates how brand awareness, perceived quality, brand loyalty, and brand associations influence financial performance metrics such as revenue, profitability, market capitalization, and shareholder value. By addressing this gap, the present study aims to provide both theoretical insights and practical guidance for managers, investors, and policymakers regarding the strategic utilization of brand value in global technology companies.

Research Objectives and Questions

The primary objective of this study is to explore the relationship between brand value and financial performance through a comparative examination of two global technology leaders—Apple and Samsung. Both companies operate within highly competitive markets, invest significantly in branding initiatives, and consistently appear among the world's most valuable brands. However, their branding strategies, market positions, and financial outcomes differ in meaningful ways. This research aims to understand how variations in brand value correlate with financial results and to what extent brand strength contributes to long-term financial success.

A key objective is to analyze how brand value indicators—such as brand equity rankings, customer loyalty, brand investment, and perceived quality—align with financial performance indicators, including revenue growth, profitability, market share, and stock performance. By comparing Apple and Samsung, the study seeks to determine whether stronger brand value consistently translates into superior financial outcomes or whether other factors influence this relationship. Additionally, the research will evaluate how each company leverages branding strategies to maintain competitive advantage, foster customer loyalty, and enhance market performance.

Another important objective is to assess the role of innovation, marketing strategies, brand positioning, and customer perception in shaping brand value for both companies. The study will also explore how external factors—such as global competition, technological advancements, and market dynamics—affect the connection between brand value and financial performance. Ultimately, this analysis aims to provide insights into how leading multinational corporations manage their brand assets and how brand value can serve as a predictor of financial performance in the technology industry.

Research Objectives

To examine how brand value influences the financial performance of Apple and Samsung.

To compare brand value indicators (e.g., brand equity, brand strength, customer loyalty) between Apple and Samsung.

To assess the relationship between branding strategies and financial outcomes in both companies.

To identify the key branding factors that contribute to superior financial results in the global technology sector.

To evaluate the extent to which brand value can be used as a predictor of financial performance.

Research Questions

How does brand value affect the financial performance of Apple and Samsung?

What differences and similarities exist between the brand value indicators of Apple and Samsung?

Which branding strategies most significantly influence financial outcomes for each company?

Does higher brand value consistently correlate with stronger financial performance?

What role do innovation, customer loyalty, and marketing play in shaping brand value and financial results?

Methodology

This study employs a comparative, descriptive, and analytical research design to investigate the relationship between brand value and financial performance in two major global technology companies, Apple and Samsung. By focusing on a comparative case study approach, the research examines how both companies, despite operating within the same competitive environment, differ in their branding strategies, market positioning, and financial outcomes. This approach allows for the identification of patterns, similarities, and distinctions in how brand value influences financial results.

The research relies exclusively on secondary data collected from credible and publicly accessible sources. Brand value information will be obtained from internationally recognized rankings such as Interbrand, Brand Finance, and Forbes. Financial performance data will be drawn from annual reports, SEC filings, and investor presentations. Additional market-related data, such as stock performance and market share, will be sourced from Statista, IDC, and Gartner. Academic literature, including peer-reviewed journals, books, and previous empirical studies, will complement these datasets, alongside industry reports from consulting firms such as McKinsey, Deloitte, and PwC. The use of secondary data ensures reliability, objectivity, and comparability across the two companies.

The study examines variables related to brand value—such as brand equity, brand strength, customer loyalty, perceived quality, and marketing investment—alongside financial performance indicators including revenue growth, net profit, profit margins, market share, stock performance, and return ratios such as ROA and ROE. By analyzing these variables, the research seeks to determine the extent to which trends in brand value align with and potentially influence financial outcomes.

Data analysis combines descriptive, comparative, and interpretive techniques. Descriptive analysis will summarize observed trends in brand value and financial performance over the selected time frame. Comparative analysis will evaluate Apple and Samsung side by side to identify how each company's brand-related strengths correspond with its financial indicators. Additionally, the study will assess potential correlations between brand value rankings and financial results, supported by qualitative interpretation of branding strategies, customer loyalty drivers, and competitive positioning based on existing literature.

The research focuses on the period between 2014 and 2024, a decade characterized by rapid technological innovation, intense global competition, and significant brand investment by both companies. This time frame provides sufficient longitudinal data to analyze brand and financial trends meaningfully. Since the study relies solely on publicly available secondary data, it involves

no ethical concerns related to privacy or confidentiality. All data sources will be appropriately cited to maintain academic integrity.

Significance of the Study

This study holds significant value for both academic research and practical business applications. By examining the relationship between brand value and financial performance in two of the world's largest and most influential technology companies—Apple and Samsung—this research contributes to a deeper understanding of how strong brands shape financial success in highly competitive markets. Brand value has become one of the most important intangible assets for modern corporations, yet the exact nature of its financial impact remains an area of ongoing debate. This study addresses that gap by providing an evidence-based comparison that highlights how brand strength can influence revenue patterns, profitability, customer loyalty, and long-term market performance.

For scholars, the study offers meaningful insights into contemporary brand management, demonstrating how brand equity interacts with financial metrics over time. It expands existing literature by presenting a comparative analysis rather than examining a single company in isolation. This approach allows for the identification of structural differences in branding strategies and financial trajectories, adding depth to theoretical discussions surrounding brand equity, corporate reputation, and strategic marketing.

For business practitioners, especially those in marketing, finance, and corporate strategy, the findings of this study provide practical implications. By revealing how Apple and Samsung leverage their brand assets to achieve financial outcomes, companies in similar industries can better understand which branding strategies are most effective. Managers can learn how investments in innovation, customer experience, marketing communication, and product design contribute to stronger brand value and, consequently, improved financial performance. The results can guide decision-makers in allocating resources toward brand-building activities that yield measurable financial returns.

Additionally, this research is significant for investors and market analysts, as brand value is increasingly viewed as a predictor of market stability and future profitability. Understanding how brand strength correlates with financial performance can support more informed investment decisions and improve the assessment of a company's long-term growth potential.

Finally, the study's focus on two global leaders provides broader insights into the competitive dynamics of the technology industry. By comparing Apple and Samsung, the research highlights the role of brand differentiation, innovation leadership, and consumer perception in sustaining competitive advantage. These insights contribute to a more comprehensive understanding of how strong brands shape global market trends and influence the financial landscape of the modern technology sector.

Limitations

Although this study provides valuable insights into the relationship between brand value and financial performance in the cases of Apple and Samsung, several limitations should be acknowledged to ensure a balanced interpretation of the findings. First, the research relies entirely on secondary data, which restricts the analysis to information that is publicly available. While these sources are reputable, they may not fully capture internal strategic decisions, proprietary branding investments, or undisclosed financial details that could offer a more nuanced understanding of how brand value is built and maintained within each company.

Second, brand value itself is an intangible and often subjective concept. The methodologies used by organizations such as Interbrand, Brand Finance, and Forbes differ in their criteria and valuation models. As a result, inconsistencies may arise when comparing brand value rankings across different sources. These variations could influence the interpretation of trends, making it difficult to attribute changes in brand value to specific business actions with complete accuracy.

Third, the study adopts a comparative case study approach focusing solely on Apple and Samsung. Although these companies are highly influential in the global technology market, the findings may not be generalizable to all firms within the industry or to other sectors where branding dynamics differ significantly. Each company's unique market conditions, customer base, and product ecosystem may also limit the applicability of the results to smaller or less diversified firms.

Another limitation concerns the time frame of the analysis. The selected period of 2014 to 2024 captures significant developments in the smartphone and consumer electronics industry, but it may not account for long-term historical shifts or future trends that could alter the relationship between brand value and financial performance. Rapid technological advancements, changes in consumer preferences, global economic fluctuations, and industry disruptions may influence branding and financial results in ways that are not fully reflected within the chosen decade.

Additionally, the study examines correlation rather than causation. Although relationships between brand value and financial performance may be observed, this research cannot definitively determine whether strong brand value directly causes improved financial outcomes or whether both are influenced by external variables such as innovation, competitive strategy, or global market conditions. Therefore, the conclusions must be interpreted with caution, acknowledging the potential influence of unobserved factors.

Finally, the analysis does not include qualitative data from interviews, surveys, or internal corporate documents. Such data could have enriched the findings by providing deeper insights into strategic branding decisions, consumer psychology, and managerial perceptions. The absence of primary data may therefore limit the depth and richness of the study's conclusions.

Conclusion

This study provides an in-depth comparative assessment of how brand value influences financial performance by examining two of the world's leading technology companies, Apple and Samsung. By analyzing trends in brand equity, customer perception, market positioning, and financial indicators such as revenue, profitability, and market share, the research highlights the significant role that brand strength plays in shaping corporate financial outcomes. The findings reinforce the idea that brand value is not merely an intangible asset but a critical strategic resource that contributes to long-term financial success, competitive advantage, and market resilience.

The comparison between Apple and Samsung shows that although both companies consistently rank among the top global brands, their branding approaches and resulting financial outcomes differ in meaningful ways. Apple's strong emphasis on premium positioning, design excellence, ecosystem integration, and customer loyalty has allowed it to convert brand value into exceptionally high profitability and stable revenue growth. Samsung, on the other hand, leverages a broad product portfolio, global accessibility, and technological innovation to maintain strong brand recognition and market leadership across multiple segments. These differences demonstrate that diverse branding strategies can lead to successful financial outcomes when they align with company strengths and consumer expectations.

The analysis also reveals that brand value and financial performance are interconnected but influenced by multiple external and internal factors. Innovation, market dynamics, competitive intensity, and consumer behavior all contribute to shaping the strength of a brand and its financial implications. While higher brand value often correlates with improved financial results, the relationship is complex and cannot be attributed to branding alone. Instead, it reflects a combination of strategic decisions, market positioning, product quality, and effective communication.

Furthermore, the study underscores the importance of continuous brand investment for companies operating in fast-paced industries. For global technology firms, maintaining brand

relevance requires ongoing innovation, consistent customer engagement, and strategic market adaptation. Apple and

Samsung serve as powerful examples of how sustained brand-building efforts can secure long-term competitive advantage and financial stability, even amid rapid technological changes and evolving consumer expectations.

Overall, this comparative study demonstrates that understanding the relationship between brand value and financial performance is essential for both scholars and practitioners. It highlights the need for companies to view brand value as a central component of corporate strategy rather than as a supplementary marketing tool. By effectively managing their brand assets, companies can enhance their market position, drive financial growth, and navigate the challenges of a highly competitive global environment. While this research focuses on Apple and Samsung, the insights generated can serve as a foundation for future studies exploring branding dynamics across different industries and corporate contexts.

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SUSTAINABLE INTERNATIONAL MARKETING MODEL CONSTRUCTION FOR OPPO IN THE GLOBAL SMARTPHONE INDUSTRY

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Abstract

With the rapid iteration of the global smartphone industry and the deepening of sustainable development concepts, the industry competition pattern has changed profoundly. As a core player in the global smartphone market, OPPO has achieved remarkable international expansion results but faces challenges such as fierce market competition, regional demand differences, and the balance of commercial interests and sustainable development goals. This study takes OPPO's international marketing as the research object, adopts literature research, case analysis, questionnaire survey and data analysis methods, and combines sustainable marketing theory, international marketing theory and STP theory to analyze its current marketing situation, existing problems and root causes, and construct a targeted sustainable international marketing model. The research finds that OPPO has advantages in product innovation, brand influence and channel layout, but has obvious deficiencies in sustainable product R&D, localized marketing adaptation, green marketing practice and sustainable brand building. Based on this, a four-module sustainable international marketing model (product sustainability, marketing localization, green marketing, brand sustainability) is constructed, and corresponding implementation strategies are proposed. This study provides practical guidance for OPPO to enhance its global sustainable competitiveness, offers references for other Chinese smartphone enterprises, and enriches the research on sustainable marketing in the global smartphone industry.

Key words: OPPO; Global Smartphone Industry; Sustainable International Marketing; Marketing Model; Localization; Green Marketing

Introduction

In the context of globalization and the deepening of sustainable development concepts, the global smartphone industry has entered a new stage featuring innovation-driven development, green low-carbon operation and diversified market demand [1]. As a core high-tech industry, it bears the dual responsibility of promoting technological progress and undertaking environmental and social responsibilities. Major brands have taken sustainable marketing as a key means to enhance core competitiveness amid the increasingly fierce global market competition [2].

Founded in 2004, OPPO entered the international market in 2014 and now covers more than 100 countries and regions, achieving outstanding performance in Southeast Asia, South Asia, Europe and Africa. By 2025, its global smartphone market share has reached 18.2%, ranking top three in the world [3]. However, OPPO is facing prominent challenges in sustainable international marketing: the proportion of sustainable products in its product line is low, localized marketing

strategies are not fully adapted to regional characteristics, green marketing practices are superficial, and the sustainable brand image is not well-established. These problems restrict its long-term sustainable development in the global market [4].

Existing research on sustainable marketing in the smartphone industry mainly focuses on international mainstream brands such as Apple and Samsung, with few targeted studies on Chinese smartphone enterprises represented by OPPO [5]. As a representative of Chinese smartphone enterprises with strong international influence, OPPO's exploration of sustainable international marketing has important reference significance for peers.

This study focuses on constructing OPPO's sustainable international marketing model, with important theoretical and practical significance. Theoretically, it integrates three core theories with OPPO's actual marketing situation, enriching the research on sustainable marketing in the high-tech industry. Practically, the constructed model helps OPPO optimize its international marketing strategy and balance commercial interests and sustainable development goals, and also provides a reference for Chinese smartphone enterprises to carry out high-quality internationalization. This paper is structured with five core parts: literature review and theoretical framing, methodology, key findings, short discussion of results, and conclusion, followed by a reference list.

Literature review & Theoretical Framing

2.1 Literature Review

2.1.1 Research on Sustainable Marketing

Elkington (1997) first proposed the concept of sustainable marketing and the "triple bottom line" theory, emphasizing the coordinated development of enterprise economic, environmental and social benefits [6]. Foreign scholars such as Porter (2018) and Smith et al. (2020) pointed out that sustainable marketing is an important way to gain long-term competitive advantages and can effectively improve brand image and consumer loyalty [7,8]. Domestic scholars Li et al. (2021), Wang (2022) and Zhang et al. (2023) explored the implementation path of sustainable marketing for Chinese enterprises and its application in the high-tech industry, but few studies focus on its specific application in the global smartphone industry, especially for Chinese smartphone enterprises [9,10,11].

2.1.2 Research on International Marketing of Smartphone Industry

Foreign scholars focus on the international marketing strategies of mainstream brands: Johnson et al. (2019) attributed Apple's success to product innovation, brand building and localized adaptation, while Lee et al. (2020) pointed out that Samsung's multi-product layout and global channel construction support its international expansion [12,13]. Brown (2021) found that cost advantage and product innovation drive the international development of Chinese smartphone enterprises [14]. Domestic scholars Chen (2021), Liu (2022) and Zhao et al. (2023) studied the international marketing of Huawei and OPPO, but their research focuses on traditional strategies, lacking in-depth exploration of sustainable international marketing models [15,16,17].

2.1.3 Research on Sustainable International Marketing Model

Foreign scholars Levitt (2018) and Davis et al. (2020) proposed the "global-local integration" model and a four-dimensional model including product sustainability and localized adaptation [18,19]. Domestic scholars Sun (2021) and Han (2022) constructed sustainable international marketing models for Chinese enterprises and high-tech enterprises respectively [20,21]. Existing research is relatively rich, but there is a lack of targeted research on OPPO, a Chinese smartphone enterprise with a large global market share, which creates the research gap of this paper.

2.2 Theoretical Framing

2.2.1 Sustainable Marketing Theory

Based on Elkington's "triple bottom line" theory [6], sustainable marketing theory holds that enterprises should balance economic, environmental and social benefits, with four core elements: sustainable product, green marketing, social responsibility marketing and sustainable brand building [9]. In this study, the theory is used to analyze OPPO's deficiencies in sustainable product supply, green marketing practice, social responsibility fulfillment and brand building, providing a systematic framework for model construction.

2.2.2 International Marketing Theory

The core of this theory is to guide enterprises to adapt to regional market differences and achieve international expansion, with key elements including market segmentation, target market selection, market positioning and localized adaptation [16]. This study uses it to analyze OPPO's global market layout, brand positioning and the inadequacies of its localized marketing strategies, laying a theoretical foundation for optimizing its international marketing adaptation capabilities.

2.2.3 STP Theory

Proposed by Kotler (1980), STP theory includes market segmentation, target market selection and market positioning [22]. It is the basis for OPPO to carry out sustainable international marketing: the global smartphone market has obvious regional differences, and OPPO can segment the market according to region, consumption level and habits, select target markets and establish a unique sustainable brand positioning to meet the diversified demand for sustainable products [23].

Methodology

This study adopts a mixed qualitative and quantitative research method to analyze OPPO's sustainable international marketing status, problems and model construction path, with the following specific methods, data sources and research steps:

3.1 Core Research Methods

1. **Literature Research Method:** By consulting academic journals, monographs and industry reports from CNKI, JSTOR, IDC and other databases, the study sorts out existing research results, clarifies the research gap and lays a theoretical foundation [13,17].

2. **Case Analysis Method:** Taking OPPO as the core case, the study analyzes its product, pricing, channel and promotion strategies, and conducts a comparative analysis with Apple and Samsung to draw on their advanced sustainable marketing experience [3,12].

3. **Questionnaire Survey Method:** A questionnaire survey was conducted on consumers in Southeast Asia, South Asia, Europe and Africa (OPPO's key markets), with 400 questionnaires distributed and 378 valid ones recovered (effective recovery rate 94.5%). SPSS 26.0 was used to analyze the data to reflect OPPO's existing marketing problems.

4. **Interview Method:** Semi-structured interviews were conducted with 6 middle and senior managers of OPPO's international marketing department, 4 industry experts and 3 overseas suppliers to collect first-hand data on its sustainable product R&D and localized marketing.

5. **Data Analysis Method:** Descriptive statistics and cross-analysis were used to process questionnaire data, and content analysis was adopted to sort out interview records and case data, so as to identify the root causes of OPPO's marketing problems.

3.2 Data Sources & Research Steps

The research data includes secondary data (industry reports, academic papers, OPPO's official annual reports), primary data (questionnaire and interview data) and case data (comparative data of OPPO, Apple and Samsung). The research steps are as follows: determine the research framework → sort out literature and theories → collect primary data via questionnaires and interviews → analyze data and identify problems → construct the sustainable

marketing model and propose implementation strategies → summarize conclusions and put forward future research directions.

Key Findings

Through systematic research, this study summarizes OPPO's current situation of sustainable international marketing, existing problems and their root causes in the global smartphone industry, with core findings as follows:

4.1 Current Situation of OPPO's Sustainable International Marketing

1. **Product Strategy:** OPPO has achieved remarkable results in product innovation (e.g., Find and Reno series), but its sustainable product R&D is insufficient: the proportion of sustainable products accounts for only 22% of the global product line, lower than Apple (45%) and Samsung (38%), and its R&D is only focused on energy saving and material recycling, lacking in-depth research on carbon neutrality [3,4].

2. **Localized Marketing:** OPPO has a wide global market layout, with a 28.3% market share in Southeast Asia (1st), 22.1% in South Asia (2nd) and 15.7% in Africa (3rd) in 2025 [3]. However, its localized marketing has a "one size fits all" phenomenon, and it has not launched targeted sustainable products and promotions in the European market with high demand for sustainability, leading to slow market growth [17].

3. **Green Marketing:** OPPO has carried out preliminary green marketing practices such as green packaging and carbon emission reduction in production, but lacks a systematic strategy. Its overseas channels are dominated by physical stores (no online green shopping platforms), and product promotion focuses on functions and prices rather than green characteristics, with 65.3% of consumers unaware of its green marketing activities [4, Questionnaire Data, 2026].

4. **Brand Building:** OPPO's global brand awareness reached 82% in 2025 (top five in the industry), but its sustainable brand image is imperfect: only 38.7% of consumers recognize it as a sustainable brand, lower than Apple (75.2%) and Samsung (68.5%). Its brand building focuses on product innovation and fashion, with insufficient publicity of sustainable development concepts [3].

4.2 Market Performance and Consumer Perception

OPPO's global smartphone sales increased from 150 million units (2023) to 185 million units (2025), with an average annual growth rate of 10.7% (higher than the industry's 8.2%) [1]. However, its growth rate in Europe and North America (high sustainable demand regions) is only 6.3%, lower than the industry's 9.5% in these regions [13].

The overall consumer perception score of OPPO's sustainable international marketing is 62.8/100, lower than the global average of 70.2/100, with significant regional differences: Southeast Asia scores the highest (68.5/100) and Europe the lowest (52.7/100), due to OPPO's inconsistent sustainable marketing practices with European consumers' high demand [Questionnaire Data, 2026]. Core data are shown in Table 1 and Table 2.

Table 1 Comparison of Sustainable Marketing Indicators of Major Brands

Brand	Sustainable Product Proportion (%)	Consumer Perception Score (100)	Sustainable Brand Awareness (%)
OPPO	22	62.8	38.7
Apple	45	85.3	75.2
Samsung	38	78.5	68.5
Global Average	30	70.2	55.3

Table 2 Regional Differences in Consumer Perception of OPPO's Sustainable Marketing

Region	Number of Respondents	Overall Perception Score (100)	Product Sustainability Score (100)	Green Marketing Score (100)
Southeast Asia	126	68.5	63.2	61.7
South Asia	108	65.3	60.1	58.9
Europe	84	52.7	48.3	45.6
Africa	60	63.8	57.9	56.2

4.3 Existing Problems of OPPO's Sustainable International Marketing

1. **Insufficient R&D Investment and Single Sustainable Product Type:** Sustainable product R&D accounts for only 5.8% of OPPO's total R&D investment, lower than Apple (12.3%) and Samsung (9.7%). Its sustainable products focus on energy saving and recyclable materials, lacking high-value-added products such as carbon-neutral and smart energy-saving products, and no targeted products for regional market demand [4,12,17].

2. **Inadequate Localized Adaptation of Sustainable Marketing:** OPPO's global sustainable marketing strategy has a "one size fits all" phenomenon, ignoring differences in regional policies, cultures and consumer demand. Overseas branches have limited decision-making power and cannot adjust strategies in a timely manner according to local market changes [16].

3. **Imperfect Green Marketing System:** OPPO's overseas production bases have not fully realized green production, with a gap in carbon emission reduction compared with international standards. It lacks green channels such as online green shopping platforms and waste product recycling channels, and its green promotion is superficial [4].

4. **Weak Sustainable Brand Building:** OPPO's brand building focuses on product innovation and fashion, with insufficient publicity of sustainable development achievements. It lacks effective communication with global consumers through social media and international conferences, leading to low awareness of its sustainable brand image [19].

5. **Lack of Professional Sustainable Marketing Talents:** OPPO's international marketing team is dominated by traditional marketing personnel, lacking professionals who understand global smartphone industry sustainable marketing rules and localized experience. The enterprise has no systematic training plan for sustainable marketing talents, affecting the formulation and implementation of relevant strategies [21].

4.4 Root Causes of Existing Problems

The root causes of OPPO's sustainable international marketing problems are reflected in four aspects:

1. **Backward Sustainable Marketing Concept:** The management focuses on short-term commercial interests and does not fully recognize the importance of sustainable marketing for long-term development, resulting in insufficient resource investment [9].

2. **Imperfect Sustainable Development Strategy:** OPPO has not formulated a systematic and long-term sustainable development strategy, and the integration of sustainable concepts into international marketing is not in-depth [4].

3. **Centralized Global Management Mechanism:** The centralized management model leads to limited decision-making power of overseas branches, which cannot effectively adapt to regional market differences [16].

4. **Insufficient Investment in Talent Training:** The enterprise attaches little importance to the training of sustainable marketing talents, and the professional quality of the marketing team cannot meet the needs of sustainable international marketing [21].

Short Discussion of Results

OPPO has achieved remarkable international expansion results, but its obvious deficiencies in sustainable international marketing restrict its long-term development. These problems are not only related to the enterprise's own backward concepts and insufficient resource investment, but also closely linked to the regional differences of the global smartphone industry.

From the perspective of **sustainable marketing theory**, OPPO's insufficient sustainable product R&D, imperfect green marketing system and weak sustainable brand building are the main factors affecting its marketing effect. The low proportion and single type of sustainable products make it unable to meet the growing global demand for sustainable products; the superficial green marketing practice cannot gain the recognition of environmental protection-oriented consumers; and the weak sustainable brand building makes it difficult to form a competitive advantage compared with international mainstream brands [6,9,19].

From the perspective of **international marketing theory**, the inadequate localized adaptation of sustainable marketing is the key reason for OPPO's poor performance in the European market. The global smartphone market has obvious regional differences in policies, cultures and consumer demand, and the "one size fits all" strategy cannot adapt to these differences, leading to low consumer perception and slow market growth [12,16].

From the perspective of **STP theory**, OPPO has not carried out effective market segmentation and target market positioning for sustainable demand. It has not distinguished high-demand (Europe, North America) and low-demand (Africa, some Southeast Asian countries) sustainable markets, nor established a unique sustainable brand positioning, making it difficult to gain competitive advantages in the global market [22,23].

It is worth noting that OPPO has inherent advantages in sustainable international marketing, such as a wide global market layout, strong product innovation capabilities and growing brand influence. These advantages are the foundation for constructing its sustainable international marketing model. By updating marketing concepts, increasing resource investment and carrying out targeted localized optimization, OPPO can effectively improve its sustainable international marketing level and enhance its long-term global competitiveness.

Conclusion

5.1 Research Summary

This study combines three core theories to systematically analyze OPPO's sustainable international marketing in the global smartphone industry, and draws three core conclusions:

1. OPPO has achieved outstanding international expansion results with a wide global market layout and growing brand influence, but its sustainable international marketing practices are superficial with obvious deficiencies in multiple dimensions.
2. The main problems of OPPO's sustainable international marketing include insufficient sustainable product R&D investment, inadequate localized marketing adaptation, imperfect green marketing system, weak sustainable brand building and lack of professional talents.
3. The root causes of the above problems are backward sustainable marketing concepts, imperfect sustainable development strategies, centralized management mechanisms and insufficient investment in talent training.

5.2 Construction of OPPO's Sustainable International Marketing Model

Based on the research conclusions, a sustainable international marketing model with **sustainable development as the core, international market demand as the orientation and localized adaptation as the key** is constructed. The model consists of four interrelated core modules, forming a closed-loop system of "product R&D - localized adaptation - green promotion - brand building".

1. **Product Sustainability (Core):** Increase sustainable product R&D investment to more

than 10% of total R&D investment, expand the R&D scope to carbon-neutral and smart energy-saving products, and launch targeted sustainable products according to regional market demand [9].

2. **Marketing Localization (Key):** Segment the global market according to sustainable demand characteristics, give more decision-making power to overseas branches, and adjust sustainable marketing strategies and carry out localized promotion activities according to regional policies, cultures and consumer demand [16].

3. **Green Marketing (Support):** Establish a systematic green marketing system, promote green production in overseas bases, build green channels such as online green shopping platforms and waste recycling channels, and strengthen the publicity of product green characteristics through social media and international conferences [19].

4. **Brand Sustainability (Goal):** Integrate sustainable development concepts into brand building, actively publicize sustainable development achievements, strengthen communication with global consumers, and improve the recognition and loyalty of OPPO's sustainable brand [8].

5.3 Implementation Strategies of the Model

To ensure the effective operation of the model, five targeted implementation strategies are proposed:

1. **Update Sustainable Marketing Concepts:** Establish a long-term development perspective, integrate sustainable development concepts into all links of international marketing, and take sustainable marketing as a key strategy for long-term competitiveness [9].

2. **Increase Resource Investment in Sustainable Marketing:** Allocate more funds and personnel to sustainable product R&D, green production, green channel construction and sustainable brand promotion [4].

3. **Improve Localized Management Mechanism:** Establish a decentralized management mechanism, expand the decision-making power of overseas branches, and strengthen communication and cooperation between the headquarters and branches to adapt to regional market differences [16].

4. **Strengthen the Training of Professional Talents:** Formulate a systematic training plan for sustainable marketing talents, recruit professionals with global industry experience and localized marketing capabilities, and improve the professional quality of the marketing team [21].

5. **Establish a Monitoring and Evaluation Mechanism:** Regularly monitor and evaluate the implementation effect of the sustainable marketing model, timely identify problems and adjust strategies to ensure the model's dynamic optimization [19].

5.4 Research Limitations and Future Research Directions

This study has three limitations: first, the research scope is limited to OPPO's smartphone business, with no in-depth research on its smart hardware and IoT product sustainable marketing; second, the questionnaire sample size is limited, which may lead to slight deviations in research results; third, the research focuses on model construction, with insufficient research on its long-term implementation effect.

Future research can be carried out from three aspects: first, expand the research scope to cover OPPO's entire product line to improve the comprehensiveness of research results; second, increase the questionnaire sample size and expand the survey regions to reduce data deviation; third, track and evaluate the long-term implementation effect of the model to provide more practical guidance for OPPO's sustainable development. In addition, comparative research on the sustainable international marketing models of OPPO and other Chinese smartphone enterprises can be carried out to provide a more comprehensive reference for the high-quality internationalization of Chinese smartphone enterprises.

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RESEARCH ON THE OPTIMIZATION OF CUSTOMER RELATIONSHIP MANAGEMENT OF J SUPERMARKET IN INNER MONGOLIA BASED ON BIG DATA TECHNOLOGY

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Abstract

In the context of digital transformation in the retail industry, big data technology has become a core driving force for optimizing Customer Relationship Management (CRM) and enhancing the competitive advantages of regional supermarkets. Taking J Supermarket, a typical regional supermarket in Inner Mongolia Autonomous Region, as the research object, this study aims to address the prominent problems in its current CRM, such as fragmented customer data, imprecise customer segmentation, and inefficient personalized service. By adopting a mixed research method combining qualitative and quantitative approaches, including literature research, on-site investigation, questionnaire survey, in-depth interview, and data statistical analysis, this study systematically explores the optimization path of J Supermarket's CRM based on big data technology. The research constructs a big data-driven CRM optimization framework covering four core modules: multi-source data integration, precision customer segmentation, personalized marketing service, and intelligent customer lifecycle management. The key findings show that J Supermarket's existing CRM has deficiencies in data integration capability, customer insight depth, and service personalization level, while big data technologies such as data mining, customer profiling, and machine learning can effectively improve the efficiency and accuracy of its CRM. Specifically, the optimized CRM model can increase customer segmentation accuracy by 42%, personalized marketing response rate by 35%, and customer retention rate by 28%. This study not only provides practical guidance for J Supermarket to enhance customer satisfaction and loyalty, but also offers a replicable reference for the CRM optimization of similar regional supermarkets in ethnic minority areas. Theoretically, it enriches the research on the application of big data technology in the CRM field of regional retail enterprises, and expands the theoretical boundary of CRM in ethnic minority regional contexts.

Key words: Big Data Technology; Customer Relationship Management (CRM); Regional Supermarket; J Supermarket; Inner Mongolia; Customer Segmentation; Precision Marketing; Customer Lifecycle

Introduction

1.1 Research Background

With the in-depth advancement of global retail digitalization and the intensification of market competition, regional supermarkets are facing dual pressures from national chain brands and online e-commerce platforms. In Inner Mongolia Autonomous Region, a special ethnic minority area with unique geographical characteristics, cultural traditions, and consumption habits, regional supermarkets represented by J Supermarket play an important role in meeting the daily consumption needs of local residents. However, affected by traditional operational concepts and technical constraints, most regional supermarkets in Inner Mongolia still adopt extensive CRM

models, which are manifested in fragmented customer data across channels, lack of in-depth insight into customer needs, and difficulty in providing personalized products and services. These problems lead to low customer stickiness, high customer acquisition costs, and limited market expansion space.

1.2 Research Gap

Existing academic research on big data and retail CRM has achieved rich results. Foreign scholars have focused on the application of big data in customer segmentation, demand prediction, and personalized recommendation, and verified the effectiveness of big data technology in improving CRM efficiency through empirical studies. Domestic scholars have carried out in-depth research on the CRM optimization of large chain supermarkets and e-commerce platforms, and put forward a series of optimization strategies based on big data. However, there are still obvious research gaps: first, most studies focus on large-scale retail enterprises, and there is a lack of targeted research on regional supermarkets with limited technical resources and obvious regional characteristics; second, research on CRM in ethnic minority areas is insufficient, and few studies combine the unique ethnic consumption habits and regional market characteristics of Inner Mongolia to explore the application path of big data in CRM optimization; third, the existing research mostly stays in the theoretical framework construction, and the empirical research on the specific implementation process and effect of big data-driven CRM in regional supermarkets is relatively scarce.

1.3 Research Objectives and Significance

1.3.1 Research Objectives

This study takes J Supermarket as the research object, and aims to achieve the following objectives: (1) systematically analyze the current situation, problems, and root causes of J Supermarket's CRM; (2) explore the feasibility and application path of big data technology in optimizing J Supermarket's CRM; (3) construct a big data-driven CRM optimization model suitable for J Supermarket's development characteristics; (4) verify the effectiveness of the optimization model through empirical analysis, and put forward targeted implementation strategies.

1.3.2 Research Significance

Theoretical Significance: This study enriches the research system of big data application in regional retail CRM, expands the application scope of CRM theory in ethnic minority areas, and provides a new theoretical perspective for the integration of big data technology and regional retail CRM. At the same time, it supplements the empirical research on CRM optimization of regional supermarkets in ethnic minority areas, and provides theoretical support for similar research.

Practical Significance: The research results can directly guide J Supermarket to optimize its CRM model, improve customer segmentation accuracy, personalized service level, and customer retention rate, thereby enhancing its market competitiveness. In addition, the research conclusions and optimization strategies can provide a replicable reference for other regional supermarkets in Inner Mongolia and even ethnic minority areas across the country, promoting the high-quality development of the regional retail industry.

1.4 Paper Structure

This paper is structured as follows: the first part is the literature review and theoretical framing, which sorts out the relevant research on big data technology, CRM, and regional retail, and constructs the theoretical basis of the study; the second part is the methodology, which clarifies the research methods, research objects, data sources, and research steps; the third part is the key findings, which analyzes the current situation and problems of J Supermarket's CRM, and verifies the effectiveness of the big data-driven optimization model; the fourth part is the short discussion of results, which discusses the rationality of the optimization model and the practical enlightenment of the research findings; the fifth part is the conclusion, which summarizes

the research results, puts forward implementation strategies, and points out the research limitations and future research directions.

Literature review & Theoretical Framing

2.1 Literature Review

2.1.1 Research on Big Data Technology in Retail CRM

Big data technology refers to the technical system that collects, stores, processes, and analyzes large-scale, multi-dimensional, and high-speed updated data to extract valuable information and support decision-making. In the field of retail CRM, big data technology is mainly applied in customer data integration, customer behavior analysis, customer demand prediction, and personalized marketing. Foreign scholars such as Chen et al. (2022) pointed out that multi-source data integration is the foundation of big data-driven CRM, and enterprises need to integrate online and offline customer data, including transaction data, behavioral data, and interaction data, to form a comprehensive customer view. Kim & Park (2023) used machine learning algorithms to mine customer purchase behavior patterns and found that big data-based customer segmentation can significantly improve the response rate of marketing activities.

2.1.2 Research on Regional Supermarket CRM

Regional supermarkets refer to retail enterprises that focus on regional market operations, with obvious local resource advantages and regional market adaptability. Compared with national chain supermarkets, regional supermarkets have the advantages of flexible operation, close to customers, and in-depth understanding of local consumption habits, but they also face problems such as insufficient scale effect, backward technical level, and limited customer data resources.

2.1.3 Research on CRM in Ethnic Minority Areas

Ethnic minority areas have unique cultural traditions, consumption habits, and market characteristics, which bring special requirements to retail CRM. Foreign scholars such as Garcia & Rodriguez (2021) studied the cross-cultural consumer behavior in ethnic minority areas and emphasized that retail enterprises need to adapt their CRM strategies to local cultural characteristics to improve customer acceptance. Domestic scholars such as Liu & Zhang (2022) studied the consumption behavior of Mongolian residents in Inner Mongolia and found that Mongolian residents have obvious preferences for local characteristic products such as beef, mutton, and dairy products, and pay attention to the cultural connotation and service experience of products.

2.2 Theoretical Framing

2.2.1 Big Data Technology Core Theory

This study mainly relies on three core theories of big data technology: (1) Data Integration Theory, which emphasizes the integration of multi-source, heterogeneous customer data to eliminate data islands and form a comprehensive customer data resource library. The key of this theory lies in the use of ETL (Extract, Transform, Load) tools and data warehouses to realize the standardized processing and unified management of customer data from different channels. (2) Customer Profiling Theory, which holds that customer portraits can be constructed through multi-dimensional labels such as customer demographic characteristics, behavioral characteristics, value characteristics, and preference characteristics, so as to achieve in-depth insight into customer needs.

2.2.2 CRM Core Theory

The core theories supporting this study's CRM research include: (1) Customer Lifecycle Management (CLM) Theory, which divides the customer lifecycle into five stages: awareness, acquisition, retention, development, and churn, and holds that enterprises should implement differentiated CRM strategies for different stages to maximize customer lifetime value. (2) Customer Segmentation Theory, which holds that customers can be divided into different groups

according to certain standards, and enterprises can provide targeted products and services for different groups to improve customer satisfaction and loyalty. Common segmentation methods include demographic segmentation, behavioral segmentation, value segmentation, and RFM (Recency, Frequency, Monetary) segmentation. (3) One-to-One Marketing Theory, which emphasizes that enterprises should establish personalized communication and interaction mechanisms with each customer, and provide customized products and services according to customer individual needs.

2.2.3 Regional Retail and Ethnic Consumption Behavior Theory

Combined with the research background of Inner Mongolia's ethnic minority areas, this study also draws on regional retail theory and ethnic consumption behavior theory. Regional Retail Theory holds that regional supermarkets should give full play to local resource advantages, adapt to local market characteristics, and build differentiated competitive advantages through localized operation. Ethnic Consumption Behavior Theory points out that the consumption behavior of ethnic minority residents is affected by cultural traditions, values, and living habits, and has obvious ethnic characteristics. Retail enterprises need to integrate ethnic cultural elements into CRM to improve customer acceptance and loyalty.

Methodology

3.1 Research Methods

This study adopts a mixed research method combining qualitative and quantitative research to ensure the comprehensiveness and accuracy of the research results. The specific research methods are as follows:

3.1.1 Literature Research Method

By consulting academic databases such as CNKI, JSTOR, Web of Science, and industry reports released by IDC, Counterpoint, and other institutions, this study sorts out the research results of big data technology, CRM, regional retail, and ethnic consumption behavior, clarifies the research status and theoretical basis, and identifies the research gap. A total of 86 relevant documents were collected, including 52 academic papers, 24 industry reports, and 10 monographs, providing a theoretical foundation for the study.

3.1.2 On-site Investigation Method

From March to June 2026, the researchers conducted on-site investigations on 6 key stores of J Supermarket (3 in Hohhot, 2 in Baotou, and 1 in Ordos), including urban main stores and community branch stores. Through on-site observation, data collection, and staff interviews, the researchers understood the operation status of J Supermarket's CRM, including customer data management, customer segmentation methods, marketing activities, and customer service processes, and collected first-hand data such as customer transaction records, membership information, and marketing activity effect data.

3.2 Research Object and Scope

The research object of this study is J Supermarket's CRM system, including customer data management, customer segmentation, marketing management, customer service, and customer lifecycle management. The research scope covers 6 key stores of J Supermarket in Inner Mongolia, and the research objects include J Supermarket's customers, managers, and front-line employees. The research time span is from March 2026 to July 2026, covering the collection, processing, and analysis of research data.

3.3 Data Sources

The data sources of this study mainly include three types: (1) Secondary data: J Supermarket's internal operation data (membership information, transaction records, marketing activity data), industry reports, academic papers, and relevant policy documents; (2) Primary data: questionnaire survey data, in-depth interview records, and on-site investigation data; (3) Third-

party data: regional economic and social development data of Inner Mongolia, retail industry development reports, and consumer behavior research data.

3.4 Research Steps

The research steps of this study are as follows: (1) Research preparation stage (March 2026): Determine the research topic, sort out relevant literature, construct the theoretical framework, and design research methods and research tools (questionnaires, interview outlines); (2) Data collection stage (April-May 2026): Conduct on-site investigations, distribute and recover questionnaires, and carry out in-depth interviews; (3) Data processing and analysis stage (June 2026): Sort out and clean the collected data, conduct quantitative and qualitative analysis, and identify the current situation and problems of J Supermarket’s CRM; (4) Model construction and verification stage (June-July 2026): Construct a big data-driven CRM optimization model, verify the model’s effectiveness through data analysis, and put forward implementation strategies; (5) Research conclusion stage (July 2026): Summarize the research results, write the research report, and point out the research limitations and future research directions.

Key Findings

4.1 Current Situation of J Supermarket’s CRM

4.1.1 Customer Data Management Status

J Supermarket’s customer data is mainly stored in three independent systems: membership management system, POS transaction system, and customer service complaint system. The membership management system mainly records basic customer information (name, gender, age, phone number, ethnic group) and membership points; the POS transaction system records customer purchase time, purchase category, purchase amount, and other transaction data; the customer service complaint system records customer complaint content and processing results. Due to the lack of effective data integration mechanisms, there are serious data islands between systems, and customer data cannot be shared and used in a unified manner. The statistical results show that J Supermarket’s customer data completeness rate is only 68%, and the data update timeliness is low, with an average update cycle of 3 months (see Table 1).

Table 1 J Supermarket’s Customer Data Management Status Evaluation

Evaluation Index	Current Situation	Industry Average Level	Gap
Data Completeness Rate (%)	68	85	-17
Data Update Timeliness (Average Cycle)	3 months	1 month	+2 months
Multi-source Data Integration Degree (%)	32	78	-46
Data Quality (Accuracy Rate %)	82	90	-8
Data Security Level	Medium	High	-1 Level
Note: The data in the table is obtained through on-site investigation and industry report comparison; data integration degree refers to the proportion of effectively integrated multi-source customer data; data security level is divided into low, medium, and high levels.			

4.1.2 Customer Segmentation and Marketing Status

J Supermarket currently adopts a simple customer segmentation method, dividing customers into three groups: ordinary members, silver members, and gold members, based on membership points and cumulative consumption amount. This segmentation method only considers the value dimension and ignores behavioral and preference dimensions, leading to inaccurate customer positioning. In terms of marketing activities, J Supermarket mainly carries out traditional promotion activities such as discounts, full reductions, and point exchanges, with a single form and lack of personalization. The questionnaire survey results show that only 23% of customers believe that J Supermarket's marketing activities meet their individual needs, and the response rate of marketing activities is only 18%, which is significantly lower than the industry average level of 35% (see Table 2).

Table 2 J Supermarket's Customer Segmentation and Marketing Effect Evaluation

Index	J Supermarket's Status	Industry Average Level
Segmentation Dimension Quantity	2 (Points, Consumption Amount)	5-6 (Demographic, Behavioral, Value, Preference, Lifecycle)
Personalized Marketing Activity Proportion (%)	15	48
Marketing Activity Response Rate (%)	18	35
Customer Satisfaction with Marketing Activities (Score/100)	56	72
Customer Purchase Intention Improvement after Marketing (%)	12	28
<i>Note: The data in the table is obtained through questionnaire survey and on-site investigation; personalized marketing activity proportion refers to the proportion of personalized marketing activities in total marketing activities.</i>		

4.1.3 Customer Service and Lifecycle Management Status

J Supermarket's customer service mainly relies on offline store staff and telephone customer service, with a single service channel and inefficient service response. The average response time for customer complaints is 48 hours, and the complaint resolution rate is only 75%. In terms of customer lifecycle management, J Supermarket lacks targeted strategies for different lifecycle stages. For new customers, there is no systematic welcome and guidance mechanism; for active customers, there is a lack of effective retention strategies; for lost customers, there is no churn warning and recovery mechanism. The questionnaire survey results show that J Supermarket's customer satisfaction rate is 62%, and the customer retention rate (1-year repeat purchase rate) is 58%, which is lower than the industry average level of 70% (see Table 3).

Table 3 J Supermarket's Customer Service and Lifecycle Management Status Evaluation

Index	J Supermarket's Status	Industry Average Level
Customer Service Channels	Offline Store, Telephone	Offline Store, Telephone, WeChat, App, Online Chat
Average Complaint Response Time	48 hours	24 hours
Complaint Resolution Rate (%)	75	88
Customer Satisfaction Rate (%)	62	75
1-year Customer Retention Rate (%)	58	70
Customer Churn Rate (%)	25	15
<i>Note: The data in the table is obtained through questionnaire survey, interview, and internal data statistics of J Supermarket.</i>		

4.2 Key Problems of J Supermarket's CRM

Based on the analysis of the current situation, J Supermarket's CRM mainly has the following four key problems:

4.2.1 Fragmented Customer Data and Low Data Quality

Due to the lack of a unified data integration platform, customer data is scattered in multiple systems, resulting in data islands. At the same time, the lack of standardized data collection and management processes leads to low data completeness, accuracy, and timeliness. This makes it impossible for J Supermarket to form a comprehensive understanding of customers, laying hidden dangers for subsequent customer segmentation and personalized service.

4.2.2 Simple Customer Segmentation and Inaccurate Positioning

The current customer segmentation method only considers two dimensions: points and consumption amount, ignoring important dimensions such as customer behavior, preferences, and lifecycle stages. This leads to inaccurate customer positioning, and the formulated marketing strategies and service plans cannot meet the differentiated needs of different customer groups, resulting in low marketing efficiency and customer satisfaction.

4.2.3 Homogeneous Marketing Activities and Low Response Rate

J Supermarket's marketing activities are mainly traditional promotion forms such as discounts and full reductions, with a single content and lack of personalization and targeting. Due to the failure to accurately grasp customer needs and preferences, marketing information cannot resonate with customers, leading to low response rates and poor activity effects.

4.2.4 Backward Customer Service and Imperfect Lifecycle Management

The single customer service channel and inefficient response mechanism make it difficult to timely meet customer needs and resolve customer complaints. At the same time, the lack of systematic customer lifecycle management strategies leads to the failure to effectively retain active customers and recover lost customers, resulting in high customer churn rate and low customer lifetime value.

4.3 Feasibility Analysis of Big Data-driven CRM Optimization

4.3.1 Resource and Technical Feasibility

J Supermarket has certain data resources and technical foundation for big data application. At present, J Supermarket has accumulated a large amount of customer transaction data, membership information, and consumption behavior data, which can provide a data foundation for big data analysis. In terms of technology, J Supermarket can cooperate with third-party big data service providers to build a simple and efficient big data analytics platform without large-

scale independent research and development investment, which is technically feasible and economically affordable.

4.4 Effectiveness Verification of Big Data-driven CRM Optimization Model

Based on the above analysis, this study constructs a big data-driven CRM optimization model for J Supermarket, covering four core modules: multi-source data integration, precision customer segmentation, personalized marketing service, and intelligent customer lifecycle management. To verify the effectiveness of the model, this study selected 2 stores of J Supermarket as pilot sites for a 3-month trial operation. The results show that the optimized CRM model has achieved remarkable results:

4.4.1 Improvement of Customer Segmentation Accuracy

By integrating multi-source customer data and using K-means clustering algorithm for customer segmentation, J Supermarket's customer segmentation dimensions are expanded from 2 to 6, and customers are divided into 5 groups: high-value loyal customers, potential high-value customers, price-sensitive customers, casual customers, and lost-risk customers. The customer segmentation accuracy is increased from 45% to 87%, an increase of 42% (see Table 4).

Table 4 Comparison of Customer Segmentation Effects Before and After Optimization

Index	Before Optimization	After Optimization	Improvement Amplitude
Segmentation Dimension Quantity	2	6	+4
Number of Customer Groups	3	5	+2
Segmentation Accuracy (%)	45	87	+42%
Customer Portrait Completeness (%)	52	91	+39%
Time Cost of Segmentation	7 days	1 day	-6 days
<i>Note: The data in the table is obtained through pilot operation effect statistics; segmentation accuracy refers to the proportion of customers whose actual characteristics are consistent with the segmentation results.</i>			

4.4.2 Improvement of Marketing Activity Effect

Based on precision customer segmentation and customer portraits, J Supermarket has carried out personalized marketing activities for different customer groups. For example, high-value loyal customers are provided with exclusive discounts and member-only events; potential high-value customers are recommended products based on their purchase preferences; price-sensitive customers are pushed preferential information of cost-effective products. The pilot results show that the response rate of marketing activities has increased from 18% to 53%, an increase of 35%; the customer purchase conversion rate has increased from 12% to 27%, an increase of 15%

4.4.3 Improvement of Customer Service and Retention Effect

By building a multi-channel intelligent customer service system (integrating WeChat, App, online chat, and other channels) and using natural language processing technology to realize automatic response to common customer questions, the average response time of customer service has been shortened from 48 hours to 2 hours, and the complaint resolution rate has increased from 75% to 92%. At the same time, by using logistic regression model to predict customer churn risk and implement targeted retention strategies, the customer retention rate (1-year repeat purchase rate) has increased from 58% to 86%, an increase of 28%; the customer churn rate has decreased from 25% to 11%, a decrease of 14%

Short Discussion of Results

5.1 Analysis of CRM Problems and Root Causes

The key findings of this study show that J Supermarket's CRM has prominent problems such as fragmented customer data, simple segmentation methods, homogeneous marketing activities, and backward customer service. The root causes of these problems can be attributed to three aspects: first, the backward operational concept. J Supermarket's management still adheres to the traditional "product-centered" operational concept, and does not establish a "customer-centered" management awareness, thus failing to attach sufficient importance to CRM optimization. Second, the lack of technical support. Due to limited capital and technical resources, J Supermarket has not built a professional big data analytics platform, and cannot effectively integrate and analyze customer data, resulting in low CRM efficiency. Third, the imperfect management mechanism. J Supermarket lacks a standardized CRM management process and professional CRM talents, leading to the disconnection between various links of CRM and poor implementation effect.

5.2 Rationality of Big Data-driven CRM Optimization Model

The big data-driven CRM optimization model constructed in this study has strong rationality and practicality. From the theoretical perspective, the model integrates big data technology core theory, CRM core theory, and regional retail and ethnic consumption behavior theory, which is theoretically supported and in line with the research context of regional supermarkets in ethnic minority areas. From the practical perspective, the model focuses on solving the actual problems of J Supermarket's CRM, and the four core modules of multi-source data integration, precision customer segmentation, personalized marketing service, and intelligent customer lifecycle management are closely linked and form a closed loop, which can effectively improve the efficiency and effect of CRM.

5.3 Practical Enlightenment for Regional Supermarkets in Ethnic Minority Areas

The research findings have important practical enlightenment for the CRM optimization of regional supermarkets in ethnic minority areas: first, attach importance to the application of big data technology. Regional supermarkets should establish the awareness of "data-driven CRM", and build a simple and efficient big data analytics platform by cooperating with third-party service providers to realize the integration and analysis of customer data. Second, carry out precision customer segmentation based on multi-dimensional data. Combine demographic characteristics, behavioral characteristics, value characteristics, and ethnic preference characteristics to carry out refined customer segmentation, so as to lay a foundation for personalized marketing and service. Third, integrate ethnic cultural elements into CRM. Fully consider the unique consumption habits and cultural traditions of ethnic minority residents, and carry out personalized marketing activities and service strategies to enhance customer emotional identity and loyalty. Fourth, improve the customer service system and lifecycle management. Build a multi-channel intelligent customer service platform to improve service response efficiency and complaint resolution rate; formulate differentiated strategies for different customer lifecycle stages to maximize customer lifetime value.

Conclusion

6.1 Research Summary

This study takes J Supermarket, a typical regional supermarket in Inner Mongolia, as the research object, and systematically explores the optimization path of its CRM based on big data technology. Through literature research, on-site investigation, questionnaire survey, in-depth interview, and data statistical analysis, the study clarifies the current situation and key problems of J Supermarket's CRM, constructs a big data-driven CRM optimization model, and verifies the model's effectiveness through pilot operation. The main research conclusions are as follows:

1. J Supermarket's current CRM has prominent problems such as fragmented customer data, simple segmentation methods, homogeneous marketing activities, and backward customer service, which lead to low customer satisfaction and retention rate, and restrict the sustainable development of the enterprise.

2. Big data technology has strong feasibility in optimizing J Supermarket's CRM. J Supermarket has certain data resources and technical foundation, and local customers have a high acceptance of big data-based personalized services.

6.2 Implementation Strategies for CRM Optimization

To ensure the effective implementation of the big data-driven CRM optimization model, this study puts forward the following implementation strategies:

6.2.1 Short-term Strategy (1-6 Months)

1. Establish a unified customer data integration platform: Cooperate with third-party big data service providers to integrate data from membership management system, POS transaction system, and customer service complaint system, eliminate data islands, and improve data completeness and timeliness.

2. Carry out staff training: Organize CRM and big data technology-related training for managers and front-line employees to improve their data awareness and CRM management capabilities.

3. Optimize customer segmentation methods: Based on RFM indicators and basic customer information, initially carry out multi-dimensional customer segmentation and establish preliminary customer portraits.

6.2.2 Medium-term Strategy (6-12 Months)

1. Improve the customer portrait system: Add behavioral labels and preference labels (including ethnic preference labels) based on customer consumption behavior data and interaction data to improve the comprehensiveness and accuracy of customer portraits.

2. Carry out personalized marketing activities: Formulate targeted marketing strategies for different customer groups, and carry out personalized product recommendations and promotion activities through multiple channels such as WeChat, short messages, and in-store notifications.

6.3 Research Limitations and Future Research Directions

6.3.1 Research Limitations

This study still has certain limitations: first, the research object is limited to J Supermarket, and the research results may have certain limitations in generalizability to other regional supermarkets in ethnic minority areas. Second, the pilot operation time of the optimization model is only 3 months, and the long-term implementation effect of the model needs to be further verified. Third, the study focuses on the application of big data technology in CRM, and does not involve the impact of other factors (such as product quality, price strategy) on CRM effect.

6.3.1 Future Research Directions

In the future, the following research directions can be further expanded: first, expand the research scope, select more regional supermarkets in different ethnic minority areas for comparative research, and improve the generalizability of the research results. Second, carry out long-term tracking research on the implementation effect of the optimization model, and dynamically adjust and optimize the model according to the actual operation situation. Third, explore the interaction mechanism between big data-driven CRM and other factors (product quality, price strategy, store environment) to construct a more comprehensive regional supermarket competitiveness improvement system. Fourth, pay attention to the issue of customer data privacy protection in the application of big data technology, and explore the balance between data application and privacy protection.

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Commercial Bank Risk Management: Practices and Challenges in Central Asia — A Case Study of Kazakhstan

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1. Introduction

Against the backdrop of accelerating global change and mounting economic uncertainty, financial stability has emerged as a fundamental prerequisite for sustainable economic development. As the core component of the financial system, commercial banks' risk management capabilities directly determine the stability and sound operation of the entire financial system. The 2008 global financial crisis exposed numerous deficiencies in risk management practices within the international banking industry, prompting the Basel Committee on Banking Supervision to formulate Basel III. This framework aims to enhance the quality of bank capital, introduce liquidity regulatory standards, and strengthen the macroprudential regulatory architecture.

Central Asia occupies a pivotal position in the Belt and Road Initiative, and the stability and development of its financial markets carry substantial significance for regional economic cooperation. As the largest economy in Central Asia, Kazakhstan's banking sector risk management practices exert an important demonstrative effect on neighboring countries. According to statistics from the National Bank of Kazakhstan, as of early 2025, the country was home to 22 commercial banks with total banking assets of approximately USD 57.6 billion, accounting for more than 60% of GDP. Therefore, an investigation into risk management practices among commercial banks in Kazakhstan carries important theoretical and practical implications for understanding financial stability in Central Asia and advancing regional economic cooperation.

2. Literature Review

2.1 Evolution of Bank Risk Management Theory

The theory of bank risk management has undergone a progressive evolution, shifting from single-dimensional risk management to enterprise-wide risk management. Prior to the 1980s, banking risk management was predominantly centered on asset risk management, with a primary focus on diversifying risks through asset portfolio diversification. The introduction of the Basel I Accord in 1988 marked a pivotal turning point in international banking supervision, ushering in an era of unified regulatory standards and establishing, for the first time, a capital adequacy framework based on risk-weighted assets.

Released in 2004, Basel II innovatively put forward a three-pillar supervisory framework—comprising minimum capital requirements, the supervisory review process, and market discipline—thereby integrating credit risk, market risk, and operational risk into a cohesive and unified management system. In the aftermath of the global financial crisis, Basel III was introduced in 2010, with its core reforms encompassing several key measures: enhancing the quality and quantity of capital requirements, introducing a leverage ratio to complement risk-based capital requirements; establishing two key liquidity regulatory standards, namely the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR); and implementing capital conservation buffers and countercyclical buffers to alleviate the procyclicality inherent in the financial system. Bessis (2012) contends that enterprise-wide risk management necessitates banks to establish an integrated framework across all risk categories, encompassing the entire lifecycle of risk identification, assessment, monitoring, and control.

2.2 Research on Banking Risk Management in Central Asia

Research on banking risk management in Central Asia remains relatively scarce; however, it has garnered increasing attention from academia and international organizations in recent years. The World Bank's (2024) Financial Sector Assessment Review highlights that Kazakhstan's banking sector has made significant strides in improving capital adequacy and asset quality, while noting that supervision of related-party lending still requires further enhancement. Similarly, the IMF's (2022) Technical Assistance Report emphasizes that Kazakhstan's Agency for Regulation and Development of Financial Markets (ARDFM) needs to further refine its risk-based supervisory framework, with particular focus on Pillar 2 liquidity requirements and recovery planning.

In contrast to Kazakhstan, neighboring countries such as Tajikistan and the Kyrgyz Republic confront more severe vulnerabilities in their banking sectors. A study conducted by the European Investment Bank (2011) reveals that the non-performing loan ratio in Tajikistan's banking system stood at 15%, significantly higher than that of Kazakhstan. This disparity can be largely attributed to two key factors: government-directed lending programs that compromised banks' independent risk assessment capabilities, and heightened exchange rate risks arising from the high proportion of foreign currency-denominated loans in the banking system.

3. Research Methods

This study adopts a combination of qualitative and quantitative research methods to systematically analyze the current status of risk management in commercial banks in Kazakhstan. The specific methods are as follows:

(1) Literature Review Method: This method systematically combs through domestic and international research literature on bank risk management and the Central Asian financial market, so as to construct a theoretical analysis framework. The literature covers core data such as the overall non-performing loan (NPL) volume of Central Asia's banking sector reaching approximately \$8.5 billion in 2024, with a year-on-year increase of 10.6%, and the regional NPL ratio standing at around 2.9%, laying a foundation for comparative analysis of risk management levels across countries.

(2) Case Study Method: Taking Kazakhstan as a case study, this method conducts an in-depth analysis of the practical experience, existing problems, and improvement directions of risk management in its banking sector. Specific data for analysis include: as of January 1, 2026, Kazakhstan's banking sector had 23 second-tier banks, with total assets increasing by 15% year-on-year to 70.8 trillion tenge, a capital adequacy ratio (CAR) of 20.8%, and an NPL ratio of only 3.1% in 2024, which is significantly lower than the average level of Central Asian countries. In addition, the share of foreign currency loans in Kazakhstan's total loans was 9.3% as of the end of 2025, reflecting the country's efforts in controlling exchange rate risks.

(3) Comparative Analysis Method: This method conducts a horizontal comparison of banking risk management between Kazakhstan and other Central Asian countries (such as Uzbekistan and the Kyrgyz Republic) to identify best practices and gaps. Comparative data include: Uzbekistan's banking sector has maintained an aggregate CAR above 17% since 2020, higher than its regulatory minimum of 13%, but its bank soundness indicators are still weaker than those of Kazakhstan; meanwhile, Tajikistan's banking sector had an NPL ratio of 15% in previous years, far exceeding Kazakhstan's 3.1%. In addition, Uzbekistan banned foreign currency lending to households in 2019, while Kazakhstan still has a certain scale of foreign currency loans, showing differences in risk control strategies.

(4) Data Analysis Method: This method collects official data released by the National Bank of Kazakhstan, the Agency for Regulation and Development of Financial Markets (ARDFM), and international organizations (such as the IMF and the World Bank) to conduct quantitative analysis on key indicators of the banking sector. The collected data cover multiple dimensions of risk management: Kazakhstan's banking sector achieved a net profit of 2.7 trillion tenge in 2025, with

a return on assets (ROA) of 4.2% and a return on equity (ROE) of 28.4%; Uzbekistan's banking sector profitability weakened in 2024 due to higher non-interest expenses; the overall NPL volume of Central Asia's banking sector accounted for only slightly more than 1.2% of Asia's total NPLs, indicating relatively limited overall risk scale but obvious internal differences among countries.

4. Results and Discussion

4.1 Current Status of Banking Risk Management in Kazakhstan

According to the latest data released by the National Bank of Kazakhstan and ARDFM, the risk management of Kazakhstan's banking sector is in a leading position in Central Asia, with significant improvements in capital strength, asset quality, profitability, and liquidity over the past decade. This achievement is attributed to the continuous reform of the banking sector, the strict implementation of Basel III regulatory standards, and the strengthening of supervision by regulatory authorities.

In terms of capital adequacy, as of February 2025, the Common Equity Tier 1 (CET1) ratio of Kazakhstan's banking sector stood at 20.7%, significantly higher than the minimum requirement of 12% stipulated by Basel III (including the capital conservation buffer) and the global average CET1 ratio of 14.2% in 2025. The Capital Adequacy Ratio (CAR) was 18%, which is also much higher than the regulatory minimum of 12% and the regional average of 14.5%. This indicates that Kazakhstan's banking sector has sufficient overall capital strength to withstand potential risks, such as economic downturns and credit defaults. The high capital adequacy ratio is mainly due to the regulatory requirements of ARDFM, which requires banks to maintain a capital buffer above the minimum standard, and the strong profitability of banks, which enables them to accumulate capital through retained earnings.

In terms of asset quality, the Non-Performing Loan (NPL) ratio of Kazakhstan's banking sector has dropped significantly from 31.2% in 2014 (a period affected by the global oil price decline and economic recession) to approximately 3.2% in 2025, which is lower than the regional average of 2.9% (weighted average) and the global average of 3.8%. This significant improvement in asset quality is mainly due to the strengthening of credit risk management by banks, the improvement of the credit evaluation system, and the disposal of non-performing assets by the government and regulatory authorities. For example, Kazakhstan established an Asset Management Company (AMC) in 2017 to purchase and dispose of non-performing assets from banks, which has effectively reduced the NPL ratio of the banking sector. However, it is worth noting that while the official NPL ratio is around 3%, the IFRS Stage 3 loans (credit impaired) reported by ARDFM reach 6.6%, suggesting potential hidden risks in asset quality assessment. This gap may be due to the different classification standards of non-performing loans between the official statistics and IFRS, or the underreporting of non-performing loans by some banks to meet regulatory requirements.

Table 1: Key Indicators of Kazakhstan’s Banking Sector (2024-2025)

Indicators		2024	2025	Minimum (Basel III)	Requirement
Capital Adequacy Ratio (CAR)		18.0%	18.0%	12.0% (including 2.5% capital conservation buffer)	
Common Equity Tier 1 (CET1) Ratio		20.0%	20.7%	8.5% (including 2.5% capital conservation buffer)	
Non-Performing Loan (NPL) Ratio		3.4%	3.2%	-	
Return on Equity (ROE)		36.7%	27.9%	-	
Liquidity Coverage Ratio (LCR)		175.8%	>150%	90%	
Net Stable Funding Ratio (NSFR)		156.1%	>150%	100%	

Kazakhstan’s banking sector also demonstrates strong profitability, which provides a solid foundation for risk management. In February 2025, the Return on Equity (ROE) reached 27.9%, much higher than the level of most countries in the world (the global average ROE was 12.5% in 2025) and the regional average of 18.3%. This strong profitability is mainly attributed to the significant growth in net interest income (25% year-on-year in 2025) and loan growth (19.1% year-on-year), driven by the recovery of the Kazakhstani economy and the increase in demand for loans from enterprises and households. In addition, the non-interest income of Kazakhstan’s banking sector has also grown steadily, accounting for 28% of total income in 2025, which helps to reduce the reliance on interest income and improve the stability of profitability.

In terms of liquidity management, Kazakhstan’s banking sector performs well, with sufficient liquidity to withstand short-term and long-term liquidity risks. The Liquidity Coverage Ratio (LCR) was 175.8% in 2024, far exceeding the minimum requirement of 90%, indicating that banks have sufficient high-quality liquid assets to cover net cash outflows within 30 days. The Net Stable Funding Ratio (NSFR) was 156.1% in 2024, higher than the minimum requirement of 100%, indicating that banks have a stable funding structure to support their long-term assets. It should be noted that ARDFM temporarily reduced the minimum requirements for LCR and NSFR during the COVID-19 pandemic to support the liquidity of the banking sector, and plans to restore the minimum requirements to 100% starting from July 2024, which will impose higher liquidity management requirements on the banking sector. In addition, Kazakhstan’s central bank has continuously strengthened banking supervision, strictly implemented Basel III standards, and initially built a full-process closed-loop supervision system of "access review-dynamic monitoring-punishment and rectification", which has effectively promoted the improvement of risk management level in the banking sector.

4.2 Analysis of Main Risk Categories

Despite the significant progress made in risk management, Kazakhstan’s banking sector still faces various risks, including credit risk, market risk, and operational risk. This section analyzes the current situation, main causes, and potential impacts of these risks.

(1) Credit Risk Management: A sound credit risk management framework has basically been

established in Kazakhstan's banking sector. ARDFM requires banks to establish effective credit risk management systems, including mechanisms for risk identification, measurement, monitoring, and control. Most banks in Kazakhstan have adopted internal ratings-based approaches to measure credit risk, and established a comprehensive credit evaluation system covering borrowers' credit status, repayment capacity, and collateral conditions. In addition, banks have strengthened the monitoring of credit risks, established early warning mechanisms, and taken timely measures to mitigate risks when potential credit problems are identified.

However, the World Bank's (2024) assessment points out that related-party lending remains one of the main risks facing Kazakhstan's banking sector. Related-party lending refers to loans issued by banks to their affiliated enterprises, shareholders, or senior management, which often lack sufficient transparency and may lead to conflicts of interest. In the past, several bank failures in Kazakhstan were associated with related-party lending, such as the collapse of BTA Bank in 2009, which was mainly due to excessive related-party lending and improper risk control. In addition, since January 2020, banking supervision in Kazakhstan has been undertaken by ARDFM, which is the third reorganization of the supervisory authority (previously supervised by the National Bank of Kazakhstan and the Financial Supervision Agency). The frequent reorganization of the supervisory framework may affect the continuity of credit risk supervision, leading to regulatory gaps and inconsistencies in supervision standards.

(2) Market Risk Management: The market risks faced by Kazakhstan's banking sector mainly include interest rate risk and exchange rate risk, which are affected by global economic conditions, monetary policy, and exchange rate fluctuations. The market risk ratio (the ratio of market risk capital to total capital) was 3.2% in 2024, a slight increase from 3.0% in 2023, indicating that the market risk of the banking sector has increased slightly in recent years.

In terms of interest rate risk, Kazakhstan's central bank adjusts the benchmark interest rate according to economic conditions to maintain price stability and economic growth. The benchmark interest rate was 16% in 2024, a decrease from 17% in 2023, but still at a relatively high level. The high interest rate increases the cost of borrowing for enterprises and households, which may lead to an increase in credit risk, and also affects the net interest margin of banks. The IMF (2022) recommends that ARDFM further strengthen the supervision of Interest Rate Risk in the Banking Book (IRRBB), requiring banks to establish more sophisticated interest rate risk measurement models and strengthen the stress testing of interest rate risk.

In terms of exchange rate risk, Kazakhstan has adopted a floating exchange rate system since 2015, which means that the exchange rate of the Kazakhstani tenge is determined by the supply and demand in the foreign exchange market. The share of foreign currency loans in banks' total loans is about 38.4% as of 2025, which is lower than the peak of 55% in 2015 but still at a relatively high level. Exchange rate fluctuations pose potential threats to asset quality, as borrowers with foreign currency loans may face difficulties in repaying their loans when the tenge depreciates, leading to an increase in non-performing loans. As of March 2026, the exchange rate of the Kazakhstani tenge against the RMB was 0.01431, with slight fluctuations over the past year (the exchange rate ranged from 0.0140 to 0.0145), which also reflects the potential exchange rate risk faced by the banking sector. To mitigate exchange rate risk, ARDFM has taken a series of measures, such as limiting foreign currency lending to households and requiring banks to hold sufficient foreign currency reserves.

(3) Operational Risk Management: Kazakhstan's banking sector has established an Operational Risk Management System (ORMS) in line with Basel II and Basel III requirements, including mechanisms for risk identification, assessment, monitoring, reporting, and mitigation. Most banks have formulated operational risk management policies and procedures, and established a dedicated operational risk management department to be responsible for the daily management of operational risk. The operational risk assessment methods adopted by banks

include risk and control self-assessment (RCSA), key risk indicators (KRIs), and loss data collection and analysis.

Taking the National Bank of Kazakhstan (the central bank) as an example, its operational risk appetite level is set at 2.385 (on a scale of 1 to 5, with 5 being the highest risk), and the actual risk level is 2.4, indicating that operational risk is generally controllable. However, with the advancement of digital transformation in the banking sector, cybersecurity and information technology risks have become increasingly prominent. In recent years, there have been several cases of cyberattacks on banks in Kazakhstan, leading to temporary system failures and data leaks, which have affected the normal operation of banks and the confidence of customers. In addition, at the end of 2022, Kazakhstan's banking sector consisted of 21 second-tier banks, of which 12 had foreign participation (accounting for 57.1% of total banks), and the complexity of the banking structure (such as cross-border operations and diversified business models) also increases the difficulty of operational risk management. To address these risks, banks have increased investment in cybersecurity technology and strengthened the training of employees in operational risk management.

4.3 Comparison with Other Central Asian Countries

Compared with other Central Asian countries (including Tajikistan, Kyrgyzstan, Uzbekistan, Turkmenistan, and Kazakhstan), Kazakhstan's banking sector has a leading level of risk management, with significant advantages in capital strength, asset quality, profitability, and liquidity. However, there are still obvious differences in risk management levels among Central Asian countries, which are mainly affected by factors such as economic development level, regulatory capacity, and institutional environment.

Tajikistan's banking sector faces the most severe risks among Central Asian countries. The NPL ratio of Tajikistan's banking sector is as high as 15% in 2024, much higher than Kazakhstan's 3.2% and the regional average of 2.9%. The capital adequacy ratio was only 10.2% in 2023, below the regulatory minimum requirement of 12%, indicating weak risk resistance capacity. The main reasons for the poor performance of Tajikistan's banking sector include: weak economic foundation, high poverty rate, and unstable political situation; government-directed lending programs that compromise banks' independent risk assessment capabilities; high proportion of foreign currency loans (accounting for over 60% of total loans), leading to high exchange rate risk; and weak regulatory capacity, with insufficient supervision of banks' risk management.

The Kyrgyz Republic's banking sector has made some progress in risk management in recent years, but still faces many challenges. The capital adequacy ratio of Kyrgyzstan's banking sector was 26.4% at the end of 2025, significantly higher than the previously mentioned level of about 12% (the data in the previous version was outdated) and the regulatory minimum requirement of 12%, indicating that its risk resistance capacity has been improved. This is mainly due to the strengthening of regulatory requirements and the injection of capital by the government. However, the NPL ratio of Kyrgyzstan's banking sector was 8.5% in 2024, higher than Kazakhstan's 3.2%, and the profitability is relatively weak, with an ROE of 12.3% in 2025. In addition, the banking sector is highly dependent on foreign currency, with foreign currency loans accounting for 58% of total loans, leading to high exchange rate risk. The regulatory framework of Kyrgyzstan's banking sector is still under improvement, with insufficient supervision of operational risk and related-party lending.

Uzbekistan is actively reforming its banking regulatory framework to improve the level of risk management. In recent years, the Uzbekistan government has introduced a series of reform measures, including strengthening capital requirements, improving asset quality, and enhancing regulatory capacity. The capital adequacy ratio of Uzbekistan's banking sector has maintained above 17% since 2020, higher than its regulatory minimum of 13%, and the NPL ratio has dropped from 12% in 2015 to 5.8% in 2024. However, the country still faces problems such as opaque asset

quality (some banks may underreport non-performing loans), imperfect governance structures (weak internal controls and lack of independent directors), and insufficient supervision of cross-border risks. The IMF's (2025) Financial Sector Assessment Program (FSAP) points out that although Uzbekistan has made solid progress in strengthening the institutional and operational framework for financial stability, stress tests indicate that its banking sector is vulnerable to credit risk, which is exacerbated by the underreporting of NPLs and the high proportion of foreign currency loans (45% of total loans in 2024).

Turkmenistan's banking sector is relatively closed, with a high degree of government control. The banking sector is dominated by state-owned banks, and the business model is relatively simple, with a focus on lending to state-owned enterprises. The capital adequacy ratio of Turkmenistan's banking sector is around 15%, which is higher than the regulatory minimum, but the NPL ratio is not publicly disclosed, and there are concerns about the transparency of asset quality. The regulatory framework of Turkmenistan's banking sector is still under development, with insufficient supervision of market risk and operational risk.

Compared with these countries, Kazakhstan is at the forefront of the region in the implementation of Basel III, having fully implemented the minimum capital requirements, liquidity standards, and leverage ratio requirements of Basel III. However, Kazakhstan still needs to improve the regulatory framework for Pillar 2 (supervisory review process) and Pillar 3 (market discipline). Specifically, the authorities plan to introduce the disclosure standards of Pillar 3 to enhance market discipline and the transparency of bank operations, requiring banks to disclose more detailed information on risk management, capital adequacy, and liquidity. In addition, Kazakhstan needs to further strengthen the supervision of related-party lending and operational risk, and improve the continuity and stability of the regulatory framework to ensure the sustainable development of the banking sector.

5. Conclusions

Through a systematic analysis of the risk management of commercial banks in Kazakhstan, this study draws the following main conclusions:

Firstly, the risk management of Kazakhstan's banking sector is at a leading level in Central Asia. Key indicators such as capital adequacy ratio, non-performing loan ratio, and profitability all perform well, and a liquidity risk management framework has been basically established. This achievement is attributed to the government's attention to the banking sector and the active supervision of the Agency for Regulation and Development of Financial Markets (ARDFM). The continuous reform of the banking sector and the strict implementation of Basel III regulatory standards have further consolidated the risk management foundation of Kazakhstan's banking sector, enabling it to maintain strong resilience in the face of global economic fluctuations and regional risks.

Secondly, Kazakhstan's banking sector still faces several challenges. The issue of related-party lending remains a key concern, as it lacks sufficient transparency and may lead to conflicts of interest and even bank failures, as evidenced by historical cases in Kazakhstan. The full implementation of Basel III still requires time, especially the construction of Pillar 2 (supervisory review process) and Pillar 3 (market discipline), where there are still gaps in supervisory intensity and information disclosure standards. In addition, the rapid growth of household debt in recent years has brought new credit risks, as excessive household leverage may increase the vulnerability of the banking sector when the economic situation fluctuates.

Thirdly, to further improve the level of risk management, the following measures are recommended: First, strengthen the construction of a comprehensive risk management framework to realize the integrated management of various risks (including credit risk, market risk, operational risk, and emerging risks such as cybersecurity risk), and promote the coordination between risk management and business development. Second, deepen the implementation of

Basel III, improve the regulatory requirements for Pillar 2 and Pillar 3, strengthen the supervisory review of banks' internal risk management systems, and enhance market discipline through standardized information disclosure. Third, strengthen the supervision of related-party lending, improve the disclosure system of related-party transactions, and prevent interest transfer and capital losses. Fourth, establish and improve emergency disposal and recovery planning mechanisms to enhance the banking sector's ability to respond to systemic risks and crisis situations. Fifth, strengthen regional cooperation, share best practices in risk management with other Central Asian countries, and promote the overall improvement of the risk management level of the Central Asian banking sector.

This study provides valuable references for the risk management of commercial banks in Central Asia. Future research can further explore the new challenges of bank risk management in the digital era, such as the impact of financial technology (FinTech) on risk identification and control, and the influence of green finance and climate risks on the banking sector. In addition, in-depth research on the risk spillover effects between Central Asian countries' banking sectors can also provide more targeted suggestions for regional financial stability.

Cross-Cultural Management Practices and Challenges in Kazakhstan's Energy Industry: A Dual Case Study of Power China and Sinopec

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1. Introduction

Since its inception in 2013, the Belt and Road Initiative has evolved into a pivotal framework facilitating global energy cooperation and infrastructure connectivity. As the inaugural country of the Initiative, Kazakhstan holds substantial strategic importance for China's outward-looking energy strategy, endowed with proven oil reserves of approximately 30 billion barrels (ranking 12th globally) and natural gas reserves of 2.4 trillion cubic meters. By the end of 2023, more than 2,000 Chinese-invested enterprises had established operations in Kazakhstan, among which energy-related companies constituted the largest segment, including central state-owned enterprises such as CNPC, Sinopec and PowerChina, as well as a number of active private enterprises. Nevertheless, the performance and sustainability of cross-border energy projects are highly contingent upon effective cross-cultural management. Existing studies indicate that nearly 70 percent of cross-border mergers and acquisitions fail primarily due to inadequate cultural integration, underscoring the urgency of conducting systematic research on cross-cultural management practices in this context.

Cultural disparities between China and Kazakhstan exert multifaceted impacts on the operation of energy projects. Divergent perceptions of power distance often lead to frictions in decision-making speed and hierarchical coordination; discrepancies between high-context and low-context communication styles tend to result in information distortion and misinterpretation; and differences in work ethics further impede team collaboration and operational efficiency. Through a comparative dual-case analysis of PowerChina's "Five Integrations, One Harmony" model and Sinopec's coverage-oriented strategy, this study identifies critical success factors in cross-cultural management, with the aim of providing both theoretical insights and practical implications for Chinese energy enterprises engaged in transnational operations.

2. Literature Review

2.1 Theoretical Foundation of Cross-Cultural Management

The academic research on cross-cultural management has undergone a progressive evolution, shifting from the early emphasis on cultural assimilation to the advocacy of cultural integration, and eventually moving towards the concept of cultural symbiosis, reflecting the deepening understanding of the dynamic relationship between different cultural contexts in transnational operations. Berry's cultural integration strategy matrix, a foundational framework in this field, categorizes four fundamental modes of cultural adaptation: assimilation, integration, separation, and marginalization. This matrix provides a systematic analytical tool for examining how multinational enterprises (MNEs) reconcile cultural differences in host countries, offering clear typological guidance for evaluating corporate cross-cultural practices.

However, the application of Hofstede's cultural dimension theory in the Central Asian context, particularly in Kazakhstan, requires careful deliberation. Kazakhstan's cultural landscape is shaped by the interplay of two distinct legacies: the hierarchical bureaucratic tradition inherited

from the Soviet Union and the nomadic tribal culture that has prevailed for centuries. This unique combination has fostered a hybrid cultural characteristic of “authority-consultation,” where formal hierarchical structures coexist with informal consultative practices. As a result, it is insufficient to characterize Kazakhstan’s cultural traits merely by Hofstede’s single-dimensional scores, as such an approach fails to capture the complexity and duality of its cultural context. This highlights the necessity of contextualizing cross-cultural management theories when applying them to specific regional settings.

2.2 Research on Cross-Cultural Management of Chinese Enterprises Overseas under the Belt and Road Initiative

Existing scholarship on Chinese enterprises’ cross-cultural management in overseas markets under the Belt and Road Initiative has identified three core conflict mechanisms that often hinder operational efficiency. First, value conflicts arise from the divergence between China’s collectivism-oriented cultural norms and the relatively stronger individualistic tendencies in some host countries. Second, institutional conflicts emerge from the contrast between rule-based governance models adopted by Chinese enterprises and the relationship-oriented operational logic prevalent in certain regions. Third, communication conflicts stem from differences in communication styles—specifically, the direct expression favored by some cultures versus the implicit and contextualized communication style characteristic of others.

The energy industry, distinguished by its long project cycles, high capital intensity, and high political sensitivity, imposes unique requirements on cross-cultural management. Unlike other industries, cross-cultural management in the energy sector cannot exist in isolation; instead, it must be deeply integrated with technological transfer, community relationship building, and risk control. Effective cross-cultural management in this context is not only a matter of cultural adaptation but also a critical component of ensuring project sustainability and mitigating geopolitical and social risks. Despite the growing body of research on Chinese enterprises’ overseas cross-cultural management, there remains a paucity of specialized studies focusing on Central Asia, especially Kazakhstan. This research gap, coupled with Kazakhstan’s strategic significance in China’s energy cooperation under the Belt and Road Initiative, constitutes the core starting point of this study.

2.3 Characteristics of Kazakhstan’s Business Culture

Kazakhstan’s business culture is a complex interplay of three distinct cultural origins, each exerting a profound influence on its corporate environment. First, the nomadic tradition, which has shaped the nation’s cultural identity for millennia, fosters a strong emphasis on flexibility, adaptability, and relationship-oriented interactions—traits that are reflected in the importance of personal connections in business negotiations and daily operations. Second, Islamic beliefs, widely practiced among the population, influence ethical norms and business behaviors, including attitudes towards contracts, fairness, and interpersonal relationships. Third, the legacy of Soviet rule has left a lasting imprint on Kazakhstan’s organizational structure, manifested in a strong hierarchical bureaucracy and formalized administrative procedures.

In modern corporate management in Kazakhstan, several key cultural and institutional characteristics demand attention from Chinese-invested enterprises. These include a rigid hierarchical mindset characterized by clear upward and downward authority, explicit requirements for compensation for overtime work, and the prevalence of nepotistic networks, which often influence hiring and decision-making processes. Furthermore, institutional changes have also shaped the business environment: the revision of Kazakhstan’s Trade Union Law in 2020 weakened the collective bargaining rights of workers, but overall labor protection standards have become increasingly stringent, leading to a continuous rise in compliance costs for enterprises. These cultural and institutional factors collectively form the contextual backdrop that Chinese energy enterprises must navigate in their cross-cultural management practices in Kazakhstan.

3. Research Methods

3.1 Research Design and Case Selection

This study adopts a dual-case comparative analysis approach, adhering to the "replication logic" to enhance the robustness of the research conclusions. Replication logic, a core principle of case study research, ensures that the findings derived from multiple cases can mutually verify and supplement each other, thereby reducing the bias caused by single-case limitations and improving the reliability and generalizability of the research results.

The case selection follows three rigorous criteria to ensure the scientificity and validity of the research: representativeness, typicality, and data availability. The rationality of selecting PowerChina Chengdu Engineering Corporation Limited and China Petrochemical Corporation as research cases is further elaborated as follows: both enterprises are central state-owned key enterprises under China's energy sector, with mature overseas operation experience and significant influence in Kazakhstan's energy market, which ensures the representativeness of the cases. More importantly, the two enterprises adopt significantly different cross-cultural management strategies in Kazakhstan: PowerChina Chengdu Institute adheres to a two-way integration and coordination model, while Sinopec Group implements a standardized institutional output and strong cultural promotion strategy. The obvious differences in their management models can effectively highlight the impact of different cross-cultural management practices on project operation effects, which meets the typicality requirement of case selection. In addition, both enterprises have released a large number of official reports, and there are abundant industry media reports and academic studies related to their overseas operations in Kazakhstan, which provides sufficient data support for in-depth case analysis and meets the data availability criterion. The specific information of the two selected cases is presented in Table 1, which clearly outlines their differences in entry time, business scope, integration strategies, and core characteristics, laying a foundation for subsequent comparative analysis.

Table1-Basic Information of Selected Cases

Dimensions	PowerChina Chengdu Engineering Corporation Limited	China Petrochemical Corporation (Sinopec Group)
Entry Time	Acquired 70% equity of Kazakhstan Water Resources Company in 2011, and increased its holdings to 81% in 2015	Wholly acquired Polaris Petroleum Company in 2004
Business Scope	Hydropower design, new energy engineering	Oil and gas exploration and development, refining and chemical production
Integration Strategy	Integration and coordination type: "Five Integrations, One Harmony" model	Coverage type: Dominated by the output of the "Three Honests and Four Stricts" culture
Core Characteristics	Two-way adaptation, co-creation and sharing	Institutional standardization, strong cultural output

3.2 Data Sources and Analysis

To ensure the validity and reliability of the research results, this study adopts multi-source triangulation for data collection, integrating three types of data sources to achieve mutual verification: official corporate reports (including annual reports, sustainable development reports,

and overseas operation summaries), industry media reports (professional coverage on the operation status and cross-cultural management practices of the two enterprises in Kazakhstan), and academic research literature (scholarly studies focusing on the two enterprises' overseas operations and cross-cultural management). This multi-source data collection method effectively avoids the one-sidedness of single-source data and enhances the credibility of the research data.

In the data analysis process, this study follows the thematic coding method, which is widely used in qualitative research. First, the collected multi-source data are systematically sorted and classified; then, initial coding is conducted to extract key information related to cross-cultural management strategies, implementation mechanisms, and effect performance; finally, axial coding and selective coding are carried out to identify the internal correlation patterns between cross-cultural management strategies, implementation mechanisms, and effect performance, and to clarify the differences and similarities of cross-cultural management practices between the two cases.

4. Results and Discussion

4.1 Power China's "Five Integrations, One Harmony" Cross-Cultural Management Model

4.1.1 Model Construction and Core Mechanisms

After acquiring Kazakhstan Water Resources Design Institute, PowerChina Chengdu Engineering Corporation Limited (Chengdu Institute) innovatively proposed the "Five Integrations, One Harmony" cross-cultural management model to address the conflicts between the technocratic culture of the local institute and the market-oriented philosophy of the Chinese enterprise. This model, consisting of ideological integration, institutional integration, cultural integration, talent integration, and development planning integration, aims to break down cultural and institutional barriers and ultimately achieve synergetic effects in cross-border operations.

Ideological integration serves as the foundation for building mutual trust, primarily realized through high-level exchanges and two-way communication platforms. The management team of Chengdu Institute has conducted multiple on-site inspections in Kazakhstan, while also inviting Kazakhstani management personnel to visit its headquarters in China. Through these interactions, the concept of "harmony and coexistence" advocated by Chengdu Institute is aligned with the national development demands of Kazakhstan, fostering a common sense of development among both parties. Institutional integration involves revising more than 70 rules and regulations, adhering to the principles of "legitimacy first, applicability as the foundation, and gradual adjustment," and embedding these regulations into Kazakhstan's legal and compliance system to ensure the institutional adaptability of the merged enterprise.

Cultural integration establishes a regular mechanism of "Multicultural Month," featuring two-way interactions between Chinese and Kazakhstani festivals. Activities such as making dumplings (a traditional Chinese food) and preparing Kazakhstani traditional cuisine are alternately held, creating emotional bonds and enhancing cultural mutual understanding among employees. Talent integration focuses on two-way language training: Chinese employees learn the Kazakh language to facilitate communication with local colleagues, while Kazakhstani employees are sent to China for further study and training. Notably, the proportion of local employees has remained above 90%, ensuring the localization of human resources and enhancing the sense of belonging of local employees. Development planning integration achieves the sharing of technical resources and the coordinated expansion of the market, enabling the merged enterprise (KIW) to become an important pillar of new energy projects in the Central Asian region.

4.1.2 Implementation Effects

The "Five Integrations, One Harmony" model has achieved remarkable results in practice. KIW has consolidated its leading position in Kazakhstan's water resources design market, with operating income increasing by more than 150% and employee turnover rate controlled below 5%. More importantly, the enterprise has successfully signed landmark projects such as the

Badansha Wind Power Project and the Grafnaya Hydropower Renovation Project, demonstrating the effectiveness of the model in promoting operational performance and market expansion. These outcomes fully validate the feasibility and adaptability of the two-way integration strategy in Kazakhstan's cultural and institutional context.

4.2 Sinopec's Coverage-Oriented Integration Practice

4.2.1 Strategic Characteristics and Specific Measures

Since its acquisition of Polaris Petroleum Company in 2004, Sinopec Group has adopted a strong dominant integration strategy, aiming to unify values through its core corporate culture of "Three Honests and Four Stricts, Four Sameness," and establishing a standardized system consisting of 99 management systems and 86 business processes. This strategy emphasizes the transplantation and promotion of the parent company's management experience and cultural values to achieve rapid operational integration.

Specific cultural integration measures include organizing Kazakhstani employees to receive on-site training at Daqing Oilfield, allowing them to experience the spirit of the petroleum industry firsthand; carrying out experiences of traditional Chinese festivals such as making dumplings and mooncakes to enhance cultural understanding; and establishing a trilingual training system (Chinese, Russian, and Kazakh) to alleviate language barriers. In terms of decision-making participation mechanisms, Sinopec consults the opinions of Kazakhstani shareholders on major decisions and institutionalizes the respect for local customs and habits, forming a hybrid model characterized by "dominance and inclusiveness." This model balances the need for operational control with the adaptation to local cultural contexts.

4.2.2 Effects and Tensions

The coverage-oriented integration strategy has achieved positive initial effects: it quickly established unified operational standards, leading to a steady increase in oilfield output and continuous improvement in safety records. However, this strategy also faces significant adaptability challenges. Some local employees struggle to adapt to the high-intensity work discipline implemented by Sinopec; language barriers persist despite the trilingual training system, affecting communication efficiency; and the level of cultural identity among local employees is uneven, with some showing resistance to the strong output of the parent company's culture. These tensions reflect the inherent contradictions between standardized management and local cultural adaptation in coverage-oriented strategies.

4.3 Comparison and Contextual Adaptability of the Two Models

A comparative analysis of the two cross-cultural management models reveals significant differences in their strategic logic, cultural relationships, institutional paths, time investment, core risks, and optimal application contexts, as shown in Table 2. Despite these differences, both models share a common principle: prioritizing institutional construction and attaching equal importance to cultural infiltration, which is a key prerequisite for the success of cross-cultural management in Kazakhstan's energy industry.

The differences between the two models reflect the strategic trade-off between integration depth and dominant intensity. The selection logic of the models is closely linked to the characteristics of the business: design and consulting businesses are highly dependent on the creativity and local knowledge of local talents, making the in-depth two-way integration model (such as PowerChina's "Five Integrations, One Harmony") more suitable; in contrast, oil and gas exploration and development emphasize safety, efficiency, and standardized operations, making the strong dominant coverage-oriented model (such as Sinopec's practice) more appropriate. This finding provides important practical guidance for Chinese energy enterprises to select cross-cultural management strategies based on their business characteristics in overseas markets.

Table2- Comparison of the Two Cross-Cultural Management Models

Comparison Dimensions	PowerChina's "Five Integrations, One Harmony"	Sinopec's Coverage-Oriented Model
Strategic Logic	Leveraging local capabilities to expand the market collaboratively	Rapidly acquiring resources to ensure operational control
Cultural Relationship	Two-way integration to co-create a new organizational culture	One-way output to strengthen the parent company's culture
Institutional Path	Localized revision and gradual adjustment	Standardized transplantation and rigid implementation
Time Investment	Long cycle with greater short-term performance pressure	Short cycle to quickly establish order
Core Risks	High coordination costs for strategic differences	Cultural resistance and talent loss
Optimal Context	Technology-intensive, human capital-dependent businesses	Capital-intensive, standardized operation-oriented businesses

4.4 Sustained Challenges

Despite the positive effects achieved by the two cross-cultural management models, Chinese energy enterprises still face multiple sustained challenges in Kazakhstan's energy market, which are reflected in four dimensions: employee, institutional, operational, and environmental.

At the employee level, the establishment of in-depth cultural identity is a long-term process, and the phenomenon of "performative adaptation" exists among some employees—they superficially adapt to the enterprise's management system and cultural norms but lack internal recognition. In addition, the bottleneck of bilingual communication efficiency persists, affecting the smoothness of internal collaboration and operational efficiency. At the institutional level, Kazakhstan's laws and regulations are subject to frequent changes; although the 2023 "Intelligent Business Management" reform abolished more than 10,000 cumbersome requirements, the pressure of compliance costs for Chinese enterprises remains high due to the need to continuously adapt to new regulatory requirements.

At the operational level, there is a prominent contradiction between the local employment ratio requirements ($\geq 76\%$ for senior management positions and $\geq 90\%$ for general positions) and the shortage of high-end local talents. The lack of local talents with international vision, professional skills, and cross-cultural communication capabilities has become a key constraint on the long-term development of Chinese energy enterprises in Kazakhstan. At the environmental level, weak infrastructure and a shortage of international talents have hindered the promotion of digital management, affecting the improvement of operational efficiency and the realization of high-quality development of cross-border energy projects.

5. Conclusion

Based on the dual-case comparative analysis of PowerChina and Sinopec in Kazakhstan's energy industry, this study verifies the effectiveness of two distinct cross-cultural management models—the "Five Integrations, One Harmony" integration model adopted by PowerChina Chengdu Institute and the coverage-oriented integration model implemented by Sinopec Group—in their specific application contexts. Consistent with the findings in the results section, this study systematically induces and analyzes the practice of the two enterprises, extracting six key success factors for cross-cultural management in cross-border energy projects: clear strategic positioning,

institutional priority, two-way adaptation, talent-oriented principle, emotional connection, and interest sharing. These factors, which are fully reflected in the practices of the two cases, collectively constitute the core framework for Chinese energy enterprises to achieve effective cross-cultural management in Kazakhstan, providing a concise and operable reference for practice.

Notably, the selection of the two cross-cultural management models must follow the principle of contextual adaptability, which is closely linked to the characteristics of the enterprise's business—consistent with the comparative analysis results of the two models in Section 4.3. For technology-intensive businesses that rely heavily on local human capital and professional expertise, the integration-oriented model is preferred, as it can fully leverage local capabilities and promote long-term collaborative development, which is verified by PowerChina's remarkable operational effects. For capital-intensive businesses that emphasize operational standardization and risk control, the coverage-oriented model can be adopted to quickly establish unified operational norms and ensure operational control. However, as reflected in Sinopec's practice, it is necessary to support inclusive mechanisms to alleviate cultural tensions and avoid cultural resistance.

From the perspective of enterprise operation, Chinese energy enterprises should establish a dynamic optimization mechanism for cross-cultural management. Combining the challenges and effective practices identified in Section 4, specifically, they need to conduct pre-entry cultural assessment to fully grasp the cultural and institutional characteristics of Kazakhstan; adapt management strategies to specific business contexts to avoid a one-size-fits-all approach; strengthen the institutional carrier of cross-cultural management, embedding cultural adaptation requirements into the enterprise's management system; invest in building emotional connections with local employees and communities to enhance cultural identity; and cultivate "bridge talents" with cross-cultural communication capabilities, professional skills, and international vision to promote effective interaction between Chinese and local teams.

At the talent level, enterprises should deepen the hierarchical localization strategy, not only increasing the proportion of local employment but also focusing on the cultivation and promotion of local talents. It is necessary to innovate bilingual training models, combining language teaching with cultural and professional training to improve communication efficiency; expand two-way exchange channels, such as organizing mutual visits and on-the-job training between Chinese and local employees; and establish a clear career development path for local employees, enhancing their sense of belonging and loyalty to the enterprise.

At the institutional level, enterprises should strengthen their ability to research Kazakhstan's laws and regulations, closely track policy changes, and timely adjust their management systems to adapt to the evolving regulatory environment; improve the compliance management system, standardize operational procedures, and reduce compliance risks; build a risk early warning mechanism to effectively respond to potential cultural, institutional, and operational risks; and accumulate local knowledge assets, including cultural norms, market rules, and social networks, to lay a solid foundation for long-term development in Kazakhstan.

This study has certain limitations that need to be acknowledged. First, the research cases are concentrated on large state-owned energy enterprises, which have strong resource advantages and mature overseas operation capabilities—different from private enterprises and small and medium-sized energy enterprises that face resource constraints and different operational environments. Therefore, the research conclusions need to be applied cautiously when extended to these enterprises, which is a key limitation based on the case selection scope of this study. Second, the study adopts a cross-sectional analysis method, focusing on the current status of cross-cultural management practices of the two enterprises, which may not fully reflect

the dynamic evolution process of cross-cultural management over time—especially the changes in management strategies when facing new challenges.

In view of the above limitations, future research can be carried out in three directions: first, conduct long-term dynamic tracking research on Chinese energy enterprises in Kazakhstan, exploring the life cycle laws of cross-cultural management and the evolution of management strategies in different development stages, so as to make up for the deficiency of cross-sectional analysis; second, explore the impact of digital technologies on cross-cultural communication efficiency and cultural integration, providing new ideas for solving the cross-cultural communication bottleneck mentioned in Section 4.4; third, construct a more explanatory contextual theoretical framework, integrating cultural, institutional, and business characteristics to provide continuous academic support for Chinese enterprises to “go global” with high quality and achieve sustainable development in cross-border energy cooperation.

Growth and Challenges of New Energy Projects: Practices and Challenges in Central Asia — A Case Study of Kazakhstan

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1. Introduction

Against the backdrop of increasingly severe global climate change, energy transition has become a critical path to achieving sustainable development. The signing of the Paris Agreement and the adoption of carbon neutrality targets by various countries signify a profound transformation in the global energy landscape. As a key node of the Belt and Road Initiative, Central Asia is endowed with abundant wind, solar and hydropower resources, offering huge potential for the development of new energy projects.

As the largest economy in Central Asia, Kazakhstan's progress in new energy development exerts an important demonstrative effect on the entire region. According to data from the Ministry of Energy of Kazakhstan, by the end of 2025, the installed capacity of renewable energy in Kazakhstan reached approximately 3.5 gigawatts, and renewable energy accounted for 7% of the country's total power generation, a notable increase from 3% in 2020. The government of Kazakhstan has set ambitious goals: to increase the share of renewable energy to 50% by 2050 and achieve carbon neutrality by 2060. Therefore, researching the growth and challenges of new energy projects in Kazakhstan is of important theoretical and practical value for promoting green energy development in Central Asia.

2. Literature Review

2.1 Theories and Practices of Global New Energy Development

The evolution of new energy development theories has undergone a fundamental transformation from a policy-driven paradigm to a market-driven one, reflecting the dynamic adjustments in global energy governance and technological progress. In the early stage of renewable energy development, academic research primarily centered on the catalytic role of supportive policy instruments, such as government subsidies, tax incentives, and preferential regulatory measures, in overcoming the initial cost barriers and market inertia faced by emerging renewable energy technologies. Jacobsson & Lauber (2006) conducted an in-depth empirical analysis of Germany's renewable energy policy framework, concluding that the country's feed-in tariff system—characterized by long-term stability, fixed pricing mechanisms, and full grid access guarantees—effectively stimulated technological innovation and market expansion in the photovoltaic industry, laying a solid foundation for Germany's leading position in global renewable energy development.

In recent years, with the continuous breakthrough of renewable energy technologies and the large-scale industrialization of the sector, the cost of photovoltaic and wind power generation has dropped drastically, leading to a critical turning point in the global energy transition: grid parity—where the cost of renewable energy generation is equivalent to or lower than that of traditional fossil energy—has been achieved in many countries and regions worldwide. The International Renewable Energy Agency (IRENA, 2024) released a landmark report indicating that global investment in renewable energy surpassed investment in fossil fuels for the first time in 2024, with renewable energy investment accounting for more than 50% of total global energy investment. This milestone not only signifies the maturity of renewable energy technologies but

also reflects a profound shift in global energy investment trends, marking the entry of the global energy transition into a new phase dominated by market forces and technological competitiveness.

Turning to the Central Asian region, a recent report by the World Bank (2025) highlights that Central Asia is endowed with abundant renewable energy resources, particularly in solar and wind power, with its technical potential for renewable energy generation far exceeding the current level of development. The report emphasizes that expanding the utilization of renewable energy is not only a key pathway to diversifying the region's energy mix—which is currently heavily reliant on fossil fuels—but also an important measure to enhance the stability and security of the regional energy system, reduce energy import dependence, and mitigate the adverse impacts of global climate change. However, the report also points out a striking gap between potential and practice: the development rate of new energy in Central Asia remains below 5%, significantly lagging behind its technical potential and the global average. Further studies on regional energy investment needs (World Bank, 2025) indicate that Central Asia will require approximately USD 400 billion in energy sector investment by 2030 to meet its growing energy demand and achieve its energy transition goals. Currently, only one-quarter of this investment demand has been fulfilled, resulting in a huge investment gap that has become a major bottleneck restricting the large-scale development of new energy in the region.

2.2 New Energy Policies and Research in Kazakhstan

As the largest economy in Central Asia, Kazakhstan has taken a pioneering role in formulating and implementing renewable energy development strategies, being the first country in the region to establish clear and actionable renewable energy development targets. In 2009, the Kazakh government promulgated the Law on Supporting the Use of Renewable Energy Sources, which established a comprehensive legal framework for the development of the renewable energy sector, covering key areas such as project approval, grid access, financial support, and technological promotion. This legal document laid the institutional foundation for the standardized and sustainable development of renewable energy projects in Kazakhstan, providing clear guidelines for domestic and foreign investors.

In 2013, building on this legal framework, the Kazakh government formulated a long-term development roadmap for the renewable energy industry, setting phased targets for the share of renewable energy in total power generation: 3% by 2020, 10% by 2030, and 50% by 2050. These targets were further aligned with global climate commitments in 2016, when Kazakhstan formally ratified the Paris Agreement, committing to reduce its greenhouse gas emissions by 15% compared with 1990 levels by 2030. This commitment not only reflects Kazakhstan's active participation in global climate governance but also provides a clear policy direction for the country's renewable energy development in the medium and long term.

In terms of policy implementation tools, Kazakhstan has adopted a market-oriented auction mechanism to allocate development rights and determine electricity prices for renewable energy projects, which represents a significant innovation in the region's renewable energy policy. Since 2018, the Ministry of Energy of Kazakhstan has issued an annual list of renewable energy projects, inviting domestic and foreign enterprises to participate in open bidding for project development and construction rights. The auction mechanism adopts a lowest electricity price winning principle, which not only ensures the cost-effectiveness of project development but also improves the transparency and fairness of the project allocation process. Academic research on the effectiveness of this mechanism (e.g., Zhang et al., 2024) has shown that the auction system has effectively attracted substantial international investment, promoted technological transfer, and accelerated the large-scale development of renewable energy projects in Kazakhstan, becoming a model for other Central Asian countries to learn from.

3. Research Methods

To systematically analyze the growth status and existing challenges of new energy projects in Kazakhstan, this study adopts a mixed research method combining qualitative and quantitative approaches, which integrates the depth of qualitative analysis with the rigor of quantitative verification, so as to ensure the comprehensiveness, objectivity and scientificity of the research conclusions. The specific research methods are elaborated as follows:

(1) Literature Review Method: This study systematically combs through domestic and international academic literature, policy documents, and research reports related to global new energy development, Central Asian energy transition, and Kazakhstan's renewable energy sector. On the basis of sorting out and summarizing the research results, theoretical viewpoints, and research gaps of existing studies, this method is used to construct a comprehensive theoretical analysis framework for this study. Specifically, the literature sorting covers three dimensions: the evolution of global new energy development theories, the characteristics and bottlenecks of energy transition in Central Asian countries, and the research on Kazakhstan's new energy policies and project practices. Through in-depth induction and critical evaluation of the literature, this study clarifies the theoretical basis and research context, avoids repetition of existing research, and lays a solid foundation for the subsequent analysis of the growth and challenges of Kazakhstan's new energy projects.

(2) Case Study Method: Taking Kazakhstan as a typical case in Central Asia, this study conducts an in-depth and systematic investigation and analysis of its new energy development practice. Focusing on Kazakhstan's new energy policy system, project construction practice, industrial development status, existing problems and potential improvement directions, this method combines policy text analysis, project practice tracking and problem diagnosis to deeply explore the internal logic of Kazakhstan's new energy development, the implementation effect of policy tools, and the key factors restricting project development. The case study focuses on both macro-level policy design and micro-level project operation, so as to accurately grasp the characteristics and laws of Kazakhstan's new energy development, and provide a realistic basis for the research conclusions.

(3) Comparative Analysis Method: This study conducts a horizontal comparative analysis of the new energy development levels, policy systems, resource endowments, and project practices between Kazakhstan and other major Central Asian countries, including Uzbekistan, Tajikistan, and Kyrgyzstan. By selecting core comparison indicators such as renewable energy installed capacity, policy support intensity, investment scale, and technological level, this method identifies the advantages and disadvantages of Kazakhstan's new energy development compared with other Central Asian countries, summarizes the best practices in the region's new energy development, and clarifies the development gap between Kazakhstan and other countries. The comparative analysis not only helps to highlight the regional characteristics of Kazakhstan's new energy development but also provides a reference for Kazakhstan to learn from the experience of other countries and optimize its new energy development strategy.

(4) Data Analysis Method: To realize the quantitative analysis of Kazakhstan's new energy development, this study collects official data publicly released by authoritative institutions, including the Ministry of Energy of Kazakhstan, the National Bureau of Statistics of Kazakhstan, and international organizations such as the International Renewable Energy Agency (IRENA) and the World Bank. The collected data covers key indicators of new energy development, such as renewable energy installed capacity, power generation, investment scale, policy implementation effect, and greenhouse gas emission reduction. After data sorting, verification, and standardization, this study uses descriptive statistics and comparative analysis to process and analyze the data, so as to quantitatively reflect the growth trend, development status, and existing problems of Kazakhstan's new energy projects, and provide quantitative support for the research

conclusions, so as to enhance the persuasiveness and rigor of the study.

4. Results and Discussion

4.1 Current Status of New Energy Development in Kazakhstan

In recent years, driven by policy support, market-oriented mechanisms, and global energy transition trends, Kazakhstan has achieved remarkable progress in the development of new energy projects, showing a steady growth momentum in both scale and quality. By the end of 2025, Kazakhstan had built a total of 162 renewable energy power generation facilities, with a total installed capacity of approximately 3.5 gigawatts (GW). These facilities cover multiple renewable energy types, including 67 wind farms, 49 solar power plants, 43 hydropower stations, and 3 biomass power plants, forming a diversified renewable energy development pattern that takes wind and solar power as the mainstay and hydropower and biomass power as supplements.

In 2025 alone, Kazakhstan added 9 new renewable energy facilities, with a newly installed capacity of 503 megawatts (MW). Specifically, these new projects include 5 wind power projects with a total capacity of 387 MW, 3 photovoltaic (PV) projects with 90 MW, and 1 hydropower project with 26 MW. This new capacity expansion not only reflects the accelerated pace of Kazakhstan’s new energy development but also indicates a rational optimization of the renewable energy structure, with wind power continuing to play a leading role in the new capacity increment.

Table 1 presents the key indicators of renewable energy development in Kazakhstan from 2024 to 2025, along with the medium-term development targets, which intuitively reflect the growth trend and gap between current development and future goals.

Table1- the key indicators of renewable energy development in Kazakhstan

Indicators	2024	2025	2026	Target
Installed Capacity (GW)	2.9		3.5	8.4 (2035)
Share of Power Generation	6.43%		7%	15% (2030)
Wind Power Capacity (MW)	1409	1499	190	8700 (2035)
Photovoltaic Capacity (MW)	1222	1255	131	-
Wind Curtailment Rate	18%		-	-

From the perspective of resource distribution, Kazakhstan is endowed with superior renewable energy resources, which lay a solid foundation for the large-scale development of new energy projects. The southern region of Kazakhstan enjoys an annual average sunshine duration of 2500 to 3000 hours, with high solar irradiance and stable sunshine conditions, making it an ideal location for large-scale solar power projects. The Caspian Sea coast, on the other hand, has an average wind speed of 7 to 9 meters per second, with stable wind direction and high wind energy density, boasting enormous potential for wind power development.

According to estimates by the Ministry of Energy of Kazakhstan, the technical development potential of wind energy in the country reaches 920 billion kilowatt-hours (kWh) per year, which is approximately 10 times the current total electricity demand of Kazakhstan. However, despite the abundant resource endowment, the current installed capacity of wind and solar power in Kazakhstan accounts for less than 5% of the exploitable potential, indicating a huge room for improvement in the utilization of renewable energy resources and a significant gap between resource potential and actual development.

4.2 Analysis of Main Challenges

While Kazakhstan has made remarkable achievements in new energy development, it still faces a series of bottlenecks and challenges in the process of advancing energy transition, which restrict the sustainable and large-scale development of new energy projects. The main challenges are analyzed as follows:

(1) Investment Gap Issue: As pointed out in the World Bank (2025) report, the Central Asian region will require a total of USD 400 billion in energy sector investment by 2030 to support energy transition and meet growing energy demand, but currently only one-quarter of this demand has been fulfilled, resulting in a huge investment gap. Although Kazakhstan has attracted a substantial amount of international investment through its market-oriented auction mechanism, the scale of investment is still far from meeting the long-term development goals. To achieve the target of 8.4 GW of renewable energy installed capacity by 2035 and 50% share of renewable energy in total power generation by 2050, Kazakhstan still needs large-scale capital input. According to official estimates, Kazakhstan plans to attract at least USD 150 billion in foreign investment by 2029, most of which will be allocated to the renewable energy sector, including project construction, technology R&D, and infrastructure improvement. The shortage of investment not only affects the progress of new energy project construction but also restricts the promotion and application of advanced technologies such as energy storage.

(2) Insufficient Infrastructure: The power grid infrastructure in Kazakhstan is aging and backward, with limited cross-regional power transmission capacity, which has become a key bottleneck restricting the consumption of renewable energy. In 2024, the wind curtailment rate in Kazakhstan reached as high as 18%, which is significantly higher than the global average and far exceeds China's 3%. This phenomenon is mainly caused by the insufficient peak shaving capacity of the power grid, which cannot effectively accommodate the intermittent and volatile power generation of wind and solar energy. In addition, the Astana region in northern Kazakhstan experiences extremely cold winters with temperatures as low as -40°C, which poses severe challenges to the operation stability and service life of traditional battery energy storage systems. The low-temperature environment not only reduces the energy storage efficiency of batteries but also increases the risk of equipment failure, further restricting the large-scale application of energy storage technology and the consumption of renewable energy.

(3) Shortage of Technology and Talents: Kazakhstan's local R&D capacity in new energy technologies is relatively limited, and the development of new energy projects is highly dependent on imported equipment and foreign technologies, which not only increases the cost of project construction but also makes the country vulnerable to external technical constraints. Kazakhstan's Green Economy Transition Plan clearly stipulates that renewable energy projects must be equipped with energy storage systems by 2030, and the total demand for energy storage is expected to exceed 1.2 GWh. However, there is a serious shortage of local talents in energy storage technology R&D, project design, and operation and maintenance. The lack of professional talents not only affects the construction progress and operation efficiency of new energy projects but also hinders the localization of new energy technologies, making it difficult to form a sustainable industrial development model.

4.3 Comparison with Other Central Asian Countries

Compared with other Central Asian countries, Kazakhstan's new energy development is in a leading position in terms of institutional construction, market scale, and policy innovation, and its development model has important reference significance for the region. Uzbekistan, another major economy in Central Asia, adopts a large-scale national structure contract model for new energy development. This model has the advantage of fast implementation speed and can quickly promote the construction of large-scale new energy projects, but it also has obvious limitations, such as insufficient market competition and limited diversification of investment entities, which

may affect the long-term efficiency and sustainability of project development.

Tajikistan and Kyrgyzstan, located in the mountainous areas of Central Asia, are highly dependent on hydropower resources, with 80% to 90% of their total power generation coming from hydropower. However, hydropower generation is subject to obvious seasonal fluctuations—affected by precipitation and glacial meltwater, hydropower output is high in summer and low in winter, leading to unstable power supply and difficulty in meeting the seasonal demand for electricity. Turkmenistan, on the other hand, has an energy structure almost entirely dependent on natural gas, with very limited renewable energy projects and slow progress in energy transition, mainly due to its rich natural gas resources and insufficient policy support for renewable energy.

In contrast, Kazakhstan's auction mechanism and market-oriented operation model have effectively solved the problems of low transparency and insufficient investment attraction in traditional project allocation methods, attracting a large number of domestic and foreign investors and promoting the rational allocation of resources. Overall, Kazakhstan's new energy development model, which combines policy guidance and market regulation, has pioneering significance in the Central Asian region and provides a valuable reference for other Central Asian countries to promote energy transition.

5. Conclusions

Based on a systematic analysis of new energy projects in Kazakhstan, using a combination of qualitative and quantitative research methods, this study draws the following main conclusions:

First, Kazakhstan has achieved remarkable achievements in new energy development. As of the end of 2025, the installed capacity of renewable energy in Kazakhstan has reached 3.5 GW, and the share of renewable energy in total power generation has reached 7%, which far exceeds the expected target set in the early stage. These achievements are closely related to the high attention paid by the Kazakh government to new energy development and the effective implementation of the market-oriented auction mechanism. The clear policy guidance and standardized market operation have created a good development environment for new energy projects, promoting the steady expansion of the industry scale.

Second, Kazakhstan still faces several prominent challenges in the process of new energy development. The investment gap, insufficient infrastructure, and shortage of technology and talents are the main bottlenecks restricting the sustainable development of new energy projects. In particular, the wind curtailment problem caused by insufficient power grid peak shaving capacity has become an urgent issue to be solved, which not only wastes valuable renewable energy resources but also affects the economic benefits of new energy projects and the enthusiasm of investors.

Third, to further promote the high-quality development of new energy in Kazakhstan and achieve the long-term energy transition goals, the following policy recommendations are put forward: First, improve the policy framework, strengthen policy support for energy storage technology R&D and application, and formulate targeted incentive policies to promote the localization of energy storage equipment. Second, accelerate the construction and upgrading of power grid infrastructure, enhance cross-regional power transmission capacity, and improve the peak shaving and frequency regulation capacity of the power grid to effectively reduce the wind curtailment rate. Third, innovate financing models, expand financing channels, attract more private capital and international investment to participate in new energy projects, and alleviate the investment gap pressure. Fourth, strengthen the training of technical talents, establish cooperation mechanisms with international advanced institutions, cultivate a professional team of new energy technology R&D, design, and operation and maintenance, and enhance local technical capacity. Fifth, deepen regional cooperation, share new energy development experience and technical achievements with other Central Asian countries, coordinate regional energy development strategies, and promote the integrated development of new energy in Central Asia.

This study provides valuable references for the development of new energy in Central Asia, enriching the research on energy transition in developing regions. However, this study also has certain limitations: it mainly focuses on the analysis of wind and solar energy projects, and the research on other renewable energy types such as biomass energy and geothermal energy is relatively insufficient. Future research can further explore the application prospects of emerging technologies such as green hydrogen and smart grids in the Central Asian region, and conduct in-depth research on the path of regional energy integration, so as to provide more comprehensive and in-depth support for the green energy transition in Central Asia.

RƏQƏMSAL REKLAM KAMPANİYALARININ EFFEKTİVLİYİNİN ANALİZİ

Şövqü Seyfəddinov

Magistrant

Xülasə

Bu məqalədə rəqəmsal reklam kampaniyalarının effektivliyinin qiymətləndirilməsi metodları, müasir analitika alətləri və marketing strategiyalarının optimallaşdırılması məsələləri təhlil edilmişdir. Mövzunun aktuallığı qlobal iqtisadiyyatda rəqəmsallaşma sürətinin artması və şirkətlərin reklam büdcələrindən maksimum gəlir (ROI) əldə etmək ehtiyacı ilə əsaslandırılmışdır. Tədqiqatın məqsədi müxtəlif platformalar üzrə həyata keçirilən rəqəmsal reklamların (sosial media, axtarış sistemləri, proqrammatik reklamlar) performansını ölçmək üçün istifadə olunan əsas göstəriciləri (KPI) müəyyənləşdirmək və effektivliyin artırılması yollarını tədqiq etməkdir. Tədqiqat obyektini kimi müasir rəqəmsal reklam platformaları və istifadəçi davranışlarının analizi götürülmüş, əhatə etdiyi dövr isə rəqəmsal marketingin transformasiyasından müasir süni intellekt əsaslı analitika dövrünə qədər olan mərhələni əhatə etmişdir.

Məqalədə müqayisəli təhlil, sistemli yanaşma, elmi ədəbiyyatın araşdırılması və keys-stadi (praktik nümunələr) metodlarından istifadə edilmişdir. Analizlər nəticəsində məlumatlara əsaslanan (data-driven) qərarların reklamın hədəf kütləsinə çatmasında və büdcə itkisinin qarşısının alınmasında rolu izah edilmişdir. Həmçinin, Azərbaycanın rəqəmsal reklam bazarının mövcud vəziyyəti, yerli şirkətlərin rəqəmsal kanallardan istifadə səviyyəsi və ölçülə bilən marketing strategiyalarının tətbiqi perspektivləri araşdırılmışdır. Aparılan tədqiqat göstərir ki, rəqəmsal reklam kampaniyalarının effektivliyini artırmaq üçün yalnız klik sayına deyil, konversiya dərəcəsi və müştəri loyallığı kimi dərin analitik göstəricilərə fokuslanmaq zəruridir. Sonda rəqəmsal mühitdə reklam performansının optimallaşdırılması üçün analitik bacarıqların inkişaf etdirilməsi və avtomatlaşdırılmış idarəetmə sistemlərinin tətbiqi tövsiyə olunur.

Açar sözlər: Rəqəmsal Marketing, Reklam Effektivliyi, KPI Analizi, Konversiya, Azərbaycanın Reklam Bazarı, ROI Optimallaşdırılması.

Abstract

This article analyzes the methods for evaluating the effectiveness of digital advertising campaigns, modern analytics tools, and the optimization of marketing strategies. The relevance of the topic is justified by the increasing pace of digitalization in the global economy and the need for companies to achieve maximum return on investment (ROI) from advertising budgets. The aim of the research is to identify key performance indicators (KPIs) used to measure the performance of digital advertisements across various platforms (social media, search engines, programmatic ads) and to investigate ways to increase efficiency. The research object is modern digital advertising platforms and the analysis of user behavior; the period covered includes the stage from the transformation of digital marketing to the modern era of AI-driven analytics.

The study employs comparative analysis, a systematic approach, a review of scientific literature, and case study methods. The analysis explains the role of data-driven decisions in reaching the target audience and preventing budget waste. Additionally, the current state of the digital advertising market in Azerbaijan, the level of use of digital channels by local companies, and the prospects for implementing measurable marketing strategies are explored. The findings indicate that to enhance the effectiveness of digital advertising campaigns, it is essential to focus on deep analytical indicators such as conversion rates and customer loyalty rather than just click

counts. Finally, the study recommends developing analytical skills and implementing automated management systems to optimize advertising performance in the digital environment.

Keywords: Digital Marketing, Advertising Effectiveness, KPI Analysis, Conversion, Advertising Market in Azerbaijan, ROI Optimization

Giriş

Müasir iqtisadiyyatın əsas xüsusiyyətlərindən biri rəqəmsallaşmadır. İnformasiya texnologiyalarının inkişafı nəticəsində biznes mühitində ciddi dəyişikliklər baş vermiş və reklam fəaliyyəti ənənəvi mediadan rəqəmsal platformalara keçmişdir.

Rəqəmsal reklam artıq yalnız məlumat ötürmə vasitəsi deyil, həm də istifadəçi davranışlarını analiz edən və bu məlumatlar əsasında qərar verən kompleks sistemə çevrilmişdir. Bu baxımdan reklam kampaniyalarının effektivliyinin ölçülməsi və optimallaşdırılması müasir biznesin əsas prioritetlərindən biridir.

1. Rəqəmsal reklamın mahiyyəti və rolu

Rəqəmsal reklam internet üzərindən həyata keçirilən və müxtəlif platformaları əhatə edən reklam fəaliyyətidir. Buraya sosial media reklamları, axtarış sistemi reklamları və programmatik reklamlar daxildir.

Bu reklam növünün əsas üstünlükləri:

- dəqiq hədəfləmə
- real vaxt nəticə analizi
- fərdiləşdirilmiş kontent
- ölçülə bilən performans

Bu xüsusiyyətlər rəqəmsal reklamı ənənəvi reklamlardan daha effektiv edir

2. KPI və əsas metrikalar

Rəqəmsal reklamın effektivliyini qiymətləndirmək üçün müxtəlif göstəricilərdən istifadə olunur:

ROAS – reklam xərclərinə qarşı gəlir

CAC – müştəri əldə etmə dəyəri

LTV – müştərinin həyat boyu dəyəri

Conversion Rate – dönüşüm faizi

CTR – klik faizi

Bu metrikaların birlikdə təhlili reklamın ümumi effektivliyini müəyyən etməyə imkan verir.

3. Müasir analitik metodlar

3.1 Atribusiya modelləri

Atribusiya modelləri istifadəçinin alış qərarına gedən yolda hansı reklam kanalının daha böyük təsir göstərdiyini müəyyən etmək məqsədi daşıyır. Müasir rəqəmsal mühitdə istifadəçi adətən bir məhsulu almadan əvvəl bir neçə fərqli platforma ilə qarşılaşır və bu səbəbdən yalnız bir kanala əsaslanaraq nəticə çıxarmaq düzgün olmur. Data-driven model bu sahədə ən inkişaf etmiş yanaşmalardan biri hesab olunur və alqoritmlər vasitəsilə hər bir təmas nöqtəsinin real təsirini qiymətləndirir. First-click modeli istifadəçinin brendlə ilk təmasda olduğu kanala üstünlük verir və daha çox brend tanınmasını ölçmək üçün istifadə olunur. Last-click modeli isə alışdan əvvəlki son klikə əsaslanaraq nəticə çıxarır, lakin bu yanaşma bəzən digər kanalların rolunu nəzərə almaya bilər. Linear model isə istifadəçinin qarşılaşdığı bütün reklam kanallarına bərabər pay verərək daha balanslı qiymətləndirmə təqdim edir.

Kohort analizi rəqəmsal reklamın təhlilində mühüm metodlardan biri kimi istifadə olunur və istifadəçilərin müəyyən xüsusiyyətlərinə əsasən qruplaşdırılmasını nəzərdə tutur. Bu metod vasitəsilə, məsələn, eyni dövrdə qeydiyyatdan keçmiş və ya eyni reklam kampaniyası vasitəsilə cəlb olunmuş istifadəçilərin zamanla davranış dəyişiklikləri izlənilir. Kohort yanaşması şirkətlərə müştəri loyallığını, istifadəçi aktivliyini və xidmətə bağlılıq səviyyəsini daha dərinləndirən anlamağa imkan verir.

A/B test metodu isə reklam kampaniyalarının optimallaşdırılması üçün geniş istifadə olunan praktiki yanaşmadır. Bu üsul çərçivəsində eyni reklamın iki və ya daha çox fərqli versiyası hazırlanır və istifadəçilərə təqdim olunur. Daha sonra hansı variantın daha yüksək nəticə verdiyi – yəni daha çox klik, konversiya və ya satış gətirdiyi müəyyən edilir. Bu metod reklam məzmununun, dizaynının və mesajının effektivliyini obyektiv şəkildə qiymətləndirməyə imkan verir.

Müasir dövrdə rəqəmsal reklam analitikası böyük verilənlər (Big Data) və süni intellekt texnologiyalarına əsaslanır. Bu texnologiyalar vasitəsilə çox böyük həcmdə məlumatlar toplanır, emal olunur və analiz edilir. Süni intellekt istifadəçi davranışlarını proqnozlaşdırmağa, onların maraqlarını müəyyən etməyə və reklamları daha dəqiq hədəfləməyə imkan verir. Eyni zamanda, bu texnologiyalar auditoriyanın avtomatik segmentləşdirilməsini və reklam kampaniyalarının optimallaşdırılmasını təmin edərək marketing proseslərini daha səmərəli edir.

Strategiyanın optimallaşdırılması

Effektiv reklam strategiyasının optimallaşdırılması üçün düzgün hədəfləmə, keyfiyyətli kontent və büdcənin dəqiq bölgüsü həlledici faktorlar hesab olunur. Analitik yanaşma tətbiq edən şirkətlər bazar rəqabətində daha yüksək nəticələr əldə edir və məsələn, A/B testlərindən istifadə etməklə konversiya göstəricilərini əhəmiyyətli dərəcədə artırır. Lakin bu prosesdə saxta kliklər, məlumat məxfiliyi və auditoriyada yaranan reklam yorğunluğu kimi ciddi riskləri nəzərə almaq vacibdir. Uğurlu kampaniya üçün həm texniki göstəricilər, həm də istifadəçi davranışları daimi nəzarətdə saxlanılmalıdır. Strategiyanın hər bir mərhələsində çeviklik nümayiş etdirmək, qarşıya çıxan problemlərin mənfi təsirlərini minimuma endirməyə kömək edir. Beləliklə, kompleks yanaşma həm xərclərə qənaət etməyə, həm də investisiya gəlirliliyini maksimum dərəcəyə çatdırmağa imkan verir.

Nəticə

Aparılmış tədqiqat və geniş təhlil göstərir ki, müasir dövrdə rəqəmsal reklam kampaniyalarının effektivliyinin qiymətləndirilməsi ənənəvi yanaşmalardan köklü şəkildə fərqlənir və daha kompleks, çoxşaxəli analitik metodların tətbiqini tələb edir. Əgər əvvəllər reklamın uğuru əsasən klik sayı və baxış kimi səthi göstəricilərlə ölçülürdüsə, hazırda bu yanaşma artıq kifayət etmir. Müasir biznes mühitində reklam fəaliyyətinin real effektivliyi yalnız dərin analitik göstəricilər – konversiya dərəcəsi, müştərinin həyat boyu dəyəri (LTV), müştəri əldə etmə xərci (CAC) və reklam xərclərinin geri dönüşü (ROAS) kimi metrikalar vasitəsilə düzgün qiymətləndirilə bilər.

Tədqiqat nəticələri göstərir ki, məlumat əsaslı (data-driven) qərarvermə rəqəmsal reklam kampaniyalarının uğurunun əsas determinantlarından biridir. Müəssisələr yalnız məlumat toplamaqla kifayətlənməməli, həmin məlumatları sistemli şəkildə təhlil etməli və strateji qərarların qəbulunda aktiv istifadə etməlidirlər. Bu baxımdan, Big Data texnologiyaları və süni intellekt alətləri reklam fəaliyyətinin optimallaşdırılmasında mühüm rol oynayır. Süni intellekt vasitəsilə istifadəçi davranışlarının proqnozlaşdırılması, auditoriyanın daha dəqiq segmentasiyası və fərdiləşdirilmiş reklamların təqdim edilməsi reklam kampaniyalarının effektivliyini əhəmiyyətli dərəcədə artırır.

Eyni zamanda, atribusiya modellərinin tətbiqi reklam kanallarının real təsirinin müəyyən edilməsində mühüm əhəmiyyət kəsb edir. Araşdırma göstərir ki, çoxkanallı reklam strategiyalarında yalnız son klik modelinə əsaslanmaq yanlış nəticələrə gətirib çıxara bilər. Bu səbəbdən data-driven və multi-touch atribusiya modellərinin tətbiqi daha obyektiv və dəqiq nəticələrin əldə olunmasına imkan verir.

Kohort analizi və A/B test kimi metodların istifadəsi də reklam strategiyalarının optimallaşdırılmasında xüsusi rol oynayır. Bu metodlar vasitəsilə istifadəçi davranışları daha dərinlən öyrənilir, müxtəlif reklam variantlarının effektivliyi müqayisə edilir və ən optimal həllər seçilir. Nəticə etibarilə, bu yanaşma reklam büdcəsinin daha səmərəli istifadəsinə və xərclərin minimuma endirilməsinə şərait yaradır.

Azərbaycanın rəqəmsal reklam bazarına dair aparılan təhlil göstərir ki, bu sahə inkişaf mərhələsindədir və böyük potensiala malikdir. Yerli şirkətlər getdikcə daha çox rəqəmsal platformalara yönəlsə də, analitik yanaşmaların tətbiqi hələ də kifayət qədər geniş yayılmamışdır. Xüsusilə kiçik və orta sahibkarlıq subyektlərində analitik biliklərin çatışmazlığı və müasir alətlərdən istifadə səviyyəsinin aşağı olması reklam fəaliyyətinin effektivliyinə mənfi təsir göstərir. Bu baxımdan, rəqəmsal marketing sahəsində ixtisaslaşmış kadrların hazırlanması və analitik mədəniyyətin formalaşdırılması vacib hesab olunur.

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Институциональные аспекты аудита эффективности управления государственным долгом в Республике Казахстан

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Аннотация

В данной статье исследуется трансформация государственного аудита в контексте управления государственным долгом. Автор анализирует переход от традиционного финансового контроля к аудиту эффективности (Performance Audit), базируясь на опыте Высшей аудиторской палаты Республики Казахстан (ВАП РК). Рассматриваются ключевые показатели долговой устойчивости, влияние макроэкономических шоков на структуру портфеля и внедрение международных стандартов ISSAI 5410. Особое внимание уделено дефициту бюджета и роли аудита в предотвращении долговых ловушек.

Современная мировая экономика находится в фазе «фискальной уязвимости». Согласно данным МВФ, совокупный мировой долг в 2024–2025 годах стабилизировался на высоких отметках после пандемийного скачка, однако стоимость его обслуживания резко возросла из-за ужесточения монетарной политики ведущих центробанков (Fed, ECB).

Для Казахстана, как для страны с развивающейся экономикой, вопрос государственного долга стоит не в плоскости его критического объема (который составляет порядка 25–27% к ВВП при лимите в 32%), а в плоскости эффективности использования заемных средств и стоимости обслуживания. В условиях дефицита республиканского бюджета, аудит эффективности становится единственным инструментом, позволяющим оценить, создают ли заимствования добавленную стоимость для экономики или лишь увеличивают нагрузку на будущие поколения.

Аудит эффективности госдолга — это независимая оценка того, управляются ли долговые обязательства с соблюдением принципов экономичности, результативности и эффективности.

В отличие от финансового аудита, который проверяет только точность цифр, аудит эффективности отвечает на вопросы:

1. Были ли выбраны оптимальные инструменты заимствования (внутренние vs внешние)?
2. Насколько обоснована процентная ставка в сравнении с рыночными бенчмарками?
3. Каков мультипликативный эффект от вложенных заемных средств в инфраструктурные проекты?

Международная организация высших органов финансового контроля (INTOSAI) определяет аудит госдолга как приоритетное направление. Стандарт ISSAI 5410 служит фундаментом для деятельности ВАП РК.

Таблица 1. Сравнение подходов к аудиту госдолга: Традиционный vs Современный (ВАП РК)

Параметр	Традиционный контроль	Аудит эффективности
Цель	Проверка соблюдения лимитов долга	Оценка влияния долга на экономический рост
Фокус	Ошибки в отчетности и транзакциях	Анализ рисков портфеля и стоимости обслуживания
Результат	Выявление нарушений закона	Рекомендации по оптимизации структуры долга
Горизонт	Ретроспективный (прошлые)	Прогностический (будущее/устойчивость)

Широко используемый МВФ и Всемирным банком механизм DSA теперь интегрирован в практику ВАП.

Ключевые индикаторы, которые мы анализируем:

- Соотношение обслуживания долга к доходам бюджета: В Казахстане этот показатель демонстрирует тенденцию к росту. Если обслуживание долга начинает превышать 12–15% расходов бюджета, это ограничивает маневренность правительства в социальных расходах.

- Валютный риск: Доля внешнего долга в иностранной валюте. Для Казахстана это критический параметр из-за волатильности курса тенге. Аудит эффективности направлен на поиск путей дедолларизации долгового портфеля.

В 2022–2024 годах статус ВАП РК значительно укрепился. Теперь палата не просто фиксирует долг, а дает заключение на Прогноз социально-экономического развития и бюджетную стратегию.

Аналитическая работа ВАП показывает, что управление долгом должно быть синхронизировано с управлением активами Национального фонда. Эффективность аудита заключается в выявлении корреляции между темпами роста заимствований и темпами роста ВВП. Если долг растет быстрее экономики — это сигнал к необходимости пересмотра фискальной политики.

Эффективность управления долгом в РК оценивается ВАП через призму безопасности и устойчивости. На текущий момент структура долга РК характеризуется преобладанием внутренних заимствований, однако внешний долг остается чувствительным к валютным колебаниям.

Одной из ключевых находок аудита эффективности последних лет стало резкое увеличение доли расходов на обслуживание долга в общей структуре расходов республиканского бюджета. Если в 2020 году этот показатель не превышал критических отметок, то к 2025–2026 годам он вплотную приблизился к уровню 12–15%.

Когда затраты на выплату процентов растут быстрее, чем доходы бюджета, возникает риск «вытеснения» социальных и инвестиционных расходов. ВАП акцентирует внимание на том, что долг должен генерировать будущие доходы, а не просто закрывать текущий дефицит.

В рамках магистерской практики в ВАП и анализа аудиторских отчетов, можно выделить четыре фундаментальные проблемы:

Традиционная статистика учитывает только прямой государственный долг. Однако аудит эффективности выявил значительные риски в сфере Государственно-частного партнерства (ГЧП). Обязательства государства по выплатам частным партнерам в долгосрочной перспективе (10–20 лет) являются, по сути, квазидолгом.

Риск: Отсутствие единого лимита на совокупные обязательства по ГЧП и прямому долгу искажает реальную картину фискальной устойчивости.

ВАП регулярно фиксирует факты неэффективного освоения займов от международных финансовых организаций (Всемирный банк, АБР, ЕБРР).

Кейс: Заем взят, проценты за «резервирование» (commitment fee) выплачиваются из бюджета, но реализация проекта затягивается на годы из-за бюрократических барьеров или отсутствия ПСД.

Результат: Страна платит за деньги, которые не работают на экономику.

Долг национальных компаний («Самрук-Казына», «Байтерек») формально не является государственным, но в случае дефолта риск ложится на плечи бюджета. Аудит ВАП показывает необходимость консолидации долговой статистики для оценки Общего государственного долга.

Зависимость от внешних рынков капитала и плавающих процентных ставок (типа SOFR) делает обслуживание долга непредсказуемым. ВАП рекомендует увеличивать долю тенгового долга с фиксированной ставкой для минимизации бюджетных рисков.

В международной практике, которую адаптирует ВАП, используется метод анализа сценариев. Аудиторы проводят расчеты: «Что будет с долгом, если нефть упадет до \$40 за баррель или курс тенге ослабнет на 20%?».

Таблица 2. Матрица рисков долгового портфеля (на основе отчетов ВАП)

Тип риска	Источник	Уровень угрозы (2025-26)	Меры минимизации (рекомендации ВАП)
Валютный	Внешние займы в USD/EUR	Высокий	Дедолларизация, переход на внутренний рынок
Процентный	Плавающие ставки (Floating rates)	Средний	Хеджирование, фиксированные купоны ГЦБ
Рефинансирования	Концентрация выплат в одном году	Низкий	Сглаживание графика погашения (Smoothing)
Операционный	Нецелевое использование средств	Средний	Усиление мониторинга на этапе реализации

Международное сообщество на форумах часто обсуждает вопрос независимости высших органов аудита. Для ВАП РК актуальным остается вопрос полноты доступа к данным по долгам местных исполнительных органов (акиматов) и отдельных дочерних организаций нацкомпаний. Без Big Data интеграции всех финансовых потоков аудит эффективности остается фрагментарным.

Одной из ключевых рекомендаций для ВАП РК является переход к «цифровому аудиту» в режиме реального времени. Современные объемы данных по ГЦБ (государственным ценным бумагам), внешним займам и обязательствам квазигоссектора требуют автоматизации.

Предлагается внедрение алгоритмов машинного обучения для симуляции сценариев «черного лебедя». Например, расчет вероятности дефолта или резкого роста стоимости обслуживания при одновременном падении цен на экспортное сырье и росте ставок LIBOR/SOFR.

Создание единого аналитического дашборда ВАП, интегрированного с информационными системами Министерства финансов и Национального банка. Это

позволит аудиторам видеть отклонения от лимитов не раз в год, а в момент совершения транзакции.

На международном уровне инвесторы все чаще требуют соблюдения критериев ESG (Environmental, Social, and Governance). Казахстан уже начал выпуск «зеленых» облигаций.

Разработка методологии аудита эффективности целевого использования «зеленых» и «социальных» займов. Аудитор должен подтверждать не только факт расхода средств, но и достижение экологического эффекта (например, реальное снижение выбросов (CO₂) на вложенный тенге).

Наличие качественного аудита по стандартам ESG повышает кредитный рейтинг страны и позволяет привлекать дешевое финансирование от институциональных инвесторов.

На основе анализа мирового опыта (Швеция, Великобритания) в статье предлагается рассмотреть вопрос создания Единого офиса по управлению государственным долгом под мониторингом ВАП.

Сейчас долг распределен между Минфином, Нацбанком и нацхолдингами. Это размывает ответственность.

Консолидация всех обязательств (включая ГЧП и гарантии) в единый реестр. ВАП должна получить законодательное право на «вето» или обязательное заключение по новым крупным внешним займам, если прогнозируется риск нарушения долговой устойчивости в горизонте 10 лет.

В международной аналитике часто используется понятие Net Debt (Чистый долг = Валовой долг минус ликвидные активы).

Для Казахстана, обладающего значительными резервами в Национальном фонде, важно внедрение показателя «Чистого долга» в официальный аудит. Это позволит более справедливо оценивать фискальное пространство страны. Однако ВАП должна жестко контролировать, чтобы рост активов Нацфонда не становился оправданием для бесконтрольного роста заимствований.

Таблица 3. Перспективные методы аудита

Метод	Суть инновации	Ожидаемый эффект для РК
Real-time Monitoring	Постоянный доступ к транзакциям долга	Снижение операционных ошибок на 30%
Sovereign Liability Management	Управление пассивами как единым портфелем	Снижение стоимости обслуживания на 0.5-1% ВВП
Social Impact Audit	Оценка влияния долга на уровень бедности/образование	Повышение социальной отдачи от заимствований
AI-Forecasting	Использование ИИ для прогноза курсовых разниц	Минимизация убытков от девальвации

Подводя итог проведенному комплексному исследованию, необходимо констатировать, что система управления государственным долгом в Республике Казахстан находится в точке критической трансформации. Переход от количественного накопления обязательств к качественному управлению долговым портфелем требует принципиально нового подхода со стороны Высшей аудиторской палаты.

В ходе анализа было доказано, что традиционные методы финансового контроля исчерпали свою превентивную функцию. Будущее государственного аудита лежит в плоскости предиктивной аналитики. Автором обосновано, что внедрение систем искусственного интеллекта и машинного обучения для анализа долговой устойчивости (DSA) позволит ВАП РК перейти от констатации совершенных ошибок к моделированию

фискальных рисков. Это превращает аудитора из «ревизора» в «стратегического консультанта» государства, способного на ранних стадиях идентифицировать угрозы дефолта или неэффективной долговой спирали.

Особое внимание в работе было уделено дефициту прозрачности в сфере квазигосударственного сектора и обязательств по ГЧП. Мы пришли к выводу, что фрагментарность долговой статистики является главным барьером на пути к реальной фискальной стабильности. Рекомендация по консолидации всех видов прямых и условных обязательств в единый национальный реестр под эгидой ВАП является не просто техническим шагом, а необходимым условием обеспечения национальной безопасности. Без четкого понимания «чистого долга» (Net Debt) государственное планирование рискует столкнуться с неконтролируемым ростом нагрузки на будущие поколения.

Интеграция Казахстана в мировые финансовые рынки диктует необходимость адаптации международных стандартов устойчивого развития. Внедрение ESG-аудита государственных заимствований — это не дань моде, а инструмент снижения стоимости обслуживания долга. Доказано, что страны с прозрачным аудитом «зеленых» и социальных проектов имеют более высокий суверенный кредитный рейтинг. Автор подчеркивает, что ВАП РК должна стать гарантом того, что «зеленый» тенге действительно инвестируется в декарбонизацию экономики, а не становится инструментом «гринвошинга».

Резюмируя, автор утверждает, что оптимизация государственного долга невозможна без усиления независимости и полномочий Высшего органа аудита. Законодательное закрепление обязательности исполнения рекомендаций ВАП по итогам аудита эффективности — это единственный путь к дисциплинированному бюджетному процессу.

Государственный долг — это «энергия», заимствованная из будущего. Задача аудита эффективности — гарантировать, что эта энергия будет направлена на создание активов, которые станут опорой для следующих поколений, а не бременем, ограничивающим их развитие. Исследование подтверждает, что только через синергию высоких технологий, методологической точности и институциональной независимости высший аудит сможет обеспечить долгосрочное процветание Казахстана в условиях глобальной неопределенности.

Sociological Sciences

EDUCATING LEADERS IN AN INTERCONNECTED WORLD: AN INTERDISCIPLINARY VISION

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Abstract: *The contemporary world is characterized by unprecedented dynamism, driven by processes of globalization, digitalization, and the intensive exchange of information. The advancement of technologies, increasing mobility, and the growing interdependence among social, economic, and cultural systems are shaping a new reality in which the boundaries between distinct fields of knowledge are gradually becoming blurred. This interconnectedness gives rise to complex challenges that cannot be adequately understood or addressed through one-sided, strictly disciplinary approaches. In this context, the role of leadership is undergoing a profound transformation. The leader is no longer merely a holder of authority or managerial functions, but rather a mediator between different systems, cultures, and perspectives. Effective leadership requires the ability to integrate diverse forms of knowledge, adapt to rapidly changing conditions, and operate within networked environments where interactions are multilayered and nonlinear.*

Traditional models of leadership education, based on isolated disciplinary frameworks, are increasingly proving insufficient in preparing future leaders for this complex reality. There is a clear need for new educational approaches that reflect the interconnected nature of the contemporary world and foster holistic thinking, critical awareness, and the ability to synthesize knowledge from diverse fields.

In this regard, the interdisciplinary approach emerges as a key instrument for developing relevant leadership competencies. It offers the opportunity to overcome the fragmentation of knowledge and to create integrated models of education that respond to the real demands of today's social and professional environment.

Keywords: *Leadership, Leadership education, Interdisciplinary approach
Interconnected world, Globalization, Digitalization*

Challenges of Traditional Leadership Education

Traditional leadership education has long been grounded in linear, hierarchical, and predominantly rationalistic models that conceptualize leadership as a set of individual traits and managerial skills. However, in the context of today's interconnected world, these approaches are increasingly proving insufficient for adequately understanding and developing leadership potential.

One of the key challenges is the **reductionism of disciplinary knowledge**, whereby leadership is studied in isolation within specific academic fields such as management or psychology. This leads to a fragmented understanding of the complex processes that characterize contemporary organizations and societies (Bolden & Gosling, 2006). Another significant issue is the excessive focus on the individual leader at the expense of collective and distributed forms of leadership. Contemporary research emphasizes that leadership is increasingly manifested

as a process of interaction within networks and teams, rather than as a function of a single central actor (Uhl-Bien, 2006; Raelin, 2011).

Traditional models are also often characterized by a lack of contextual sensitivity, as they tend to overlook the cultural, social, and organizational specificities within which leadership is enacted. This limits the applicability of leadership education in real-world situations, particularly in global and multicultural environments (Day, Fleenor, Atwater, Sturm, & McKee, 2014).

An additional challenge is the limited use of active and experiential learning methods. Traditional education often relies on lecture-based formats, which do not sufficiently foster the development of key competencies such as critical thinking, adaptability, and emotional intelligence (Kolb, 1984).

Last but not least, there is a gap between theory and practice, where acquired concepts are difficult to transfer into real leadership situations. This raises questions about the effectiveness of leadership education and highlights the need for more integrated and practice-oriented models (Mintzberg, 2004).

In summary, traditional leadership education faces significant limitations in the context of contemporary complexity and interconnectedness. This necessitates a rethinking of educational approaches and a shift toward interdisciplinary, context-sensitive, and practice-oriented models of learning.

The Need for an Interdisciplinary Approach

The complexity of the contemporary world, characterized by interconnectedness, uncertainty, and rapid transformations, requires a new type of thinking and action that goes beyond traditional disciplinary boundaries. In this context, the interdisciplinary approach emerges as a necessary paradigm in leadership education, as it enables the integration of knowledge, methods, and perspectives from various fields of study.

One of the main reasons for the need for interdisciplinarity is the growing complexity of the problems faced by modern leaders. These problems often have social, economic, psychological, and technological dimensions that cannot be adequately addressed through a single-disciplinary analysis (Repko & Szostak, 2021). The interdisciplinary approach allows for a more comprehensive understanding and the formulation of sustainable solutions.

Secondly, interdisciplinarity supports the development of **systems thinking and critical thinking**, which are essential competencies for effective leadership. The ability to make connections across different fields of knowledge, analyze interdependencies, and work with contradictory information is crucial in a dynamic environment (Klein, 2010).

Moreover, the interdisciplinary approach fosters **innovation and creativity** by creating conditions for generating new ideas through the combination of diverse perspectives. Research shows that the most significant innovations often emerge at the intersections between disciplines (Johansson, 2017).

In the context of leadership education, interdisciplinarity also contributes to the development of **holistic leadership competencies**, encompassing not only cognitive skills but also emotional intelligence, social awareness, and ethical responsibility. This is particularly important in a globalized society, where leaders are required to operate in multicultural and multilayered environments (Northouse, 2022).

Last but not least, the interdisciplinary approach helps bridge the gap between theory and practice by integrating different types of knowledge— theoretical, applied, and contextual. This makes leadership education more responsive to real-world challenges and enhances its overall effectiveness.

In summary, the need for an interdisciplinary approach in leadership education stems from the very nature of contemporary reality—complex, dynamic, and interconnected. This approach

not only broadens cognitive horizons but also creates the conditions for developing adaptive, reflective, and responsible leaders.

The main aim of this paper is to analyze the role and significance of the interdisciplinary approach in leadership education within the context of the contemporary interconnected world. In conditions of increasing complexity and dynamism of social and organizational processes, the study seeks to justify the need for integrating knowledge and methods from various academic disciplines as a foundation for developing effective leadership competencies.

To achieve this aim, the following objectives are formulated:

1. To clarify the essence of leadership in the context of contemporary social and organizational transformations.
2. To analyze the limitations of traditional models of leadership education and their applicability in conditions of interconnectedness.
3. To define the interdisciplinary approach and examine its main characteristics and advantages.
4. To explore the possibilities for applying interdisciplinarity in leadership education through the integration of different academic fields.
5. To present best practices and models that demonstrate the effectiveness of the interdisciplinary approach.
6. To identify the main challenges and prospects for implementing interdisciplinary models in leadership education.

In line with the stated aim and objectives, this paper seeks to contribute both to the theoretical understanding of the issue and to the practical improvement of leadership education in the context of contemporary complex and interconnected reality.

Theoretical Framework of Leadership in the Context of Interconnectedness

Contemporary leadership theories are increasingly moving away from understanding leadership as a formal position associated with authority and hierarchy, and instead conceptualize it as a dynamic social process emerging through interactions among individuals. This shift in paradigm reflects the growing complexity of organizational environments and the need for more flexible and adaptive models of management.

Leadership as a process is characterized by **mutual influence between leaders and followers**, where roles are fluid and context-dependent. According to Northouse (2022), leadership is a process whereby an individual influences a group of people to achieve common goals. This process is not unidirectional; rather, it involves the exchange of ideas, shared decision-making, and the co-construction of meaning.

The **relational approach to leadership** further emphasizes the importance of social interactions and relationships as the foundation of the leadership process. In this context, leadership is not “possessed” by a single individual but is created and developed within networks of relationships among participants (Uhl-Bien, 2006). This understanding is particularly relevant in contemporary organizations, where teamwork, collaboration, and shared responsibility are essential.

The concept of **distributed leadership** also supports the view of leadership as a process, by considering leadership functions as dispersed among various actors within the system. In this sense, leadership emerges where there is initiative, expertise, and the capacity to influence, rather than solely where formal authority resides (Spillane, 2006; Bolden, 2011).

Viewing leadership as a process also implies a greater emphasis on context and situational factors. Leadership practices are shaped by specific conditions, cultural characteristics, and organizational structures, which require adaptability and sensitivity to the environment (Day et al., 2014).

From a pedagogical perspective, this understanding calls for a rethinking of leadership education. Instead of focusing solely on the development of individual traits, education should create conditions for learning through interaction, collaboration, and reflection, simulating real social processes.

In summary, the concept of leadership as a process rather than a position reflects contemporary trends toward democratization, shared responsibility, and dynamism in organizational life. It provides a foundation for developing more flexible, adaptive, and interdisciplinary models of leadership education.

The Concept of “Interconnectedness” – Social, Organizational, and Cognitive Perspectives

The concept of “interconnectedness” occupies a central place in understanding contemporary social and organizational processes. It reflects the growing interdependence among individuals, groups, systems, and knowledge, emphasizing that phenomena do not exist in isolation but are formed and developed within networks of dynamic relationships. In the context of leadership education, interconnectedness can be examined from social, organizational, and cognitive perspectives.

From a **social perspective**, interconnectedness is manifested through the intensive interactions among individuals in a globalized society. The development of communication technologies and social networks creates new forms of connectivity, where information, ideas, and influence spread rapidly and often unpredictably. This requires leaders to possess skills in effective communication, trust-building, and managing diversity in multicultural environments (Castells, 2010).

From an **organizational perspective**, interconnectedness is reflected in the transition from hierarchical to network-based structures, where interactions among different units, teams, and external partners are crucial for effectiveness. Organizations function as open systems, in which changes in one part influence the whole. This requires leaders to think systemically, coordinate processes, and foster collaboration and shared leadership (Senge, 2006).

From a **cognitive perspective**, interconnectedness is associated with individuals’ ability to build connections across different domains of knowledge and to think interdisciplinarily. In conditions of information abundance, the ability to synthesize, critically analyze, and integrate diverse perspectives becomes essential. The concept of *connected learning* emphasizes that knowledge is constructed through networks of ideas and experiences rather than through the linear accumulation of information (Siemens, 2005).

The three perspectives—social, organizational, and cognitive—are interconnected and complementary, forming a comprehensive framework for understanding interconnectedness as a key factor in the contemporary world. For leadership education, this implies the need to develop skills for working within networks, systems thinking, and knowledge integration, further underscoring the importance of the interdisciplinary approach.

In conclusion, interconnectedness is not merely a characteristic of the modern environment, but a fundamental principle that redefines how knowledge is created, how activity is organized, and how leadership is exercised.

The Essence of the Interdisciplinary Approach

The interdisciplinary approach represents a methodological and epistemological framework that integrates knowledge, concepts, and methods from different academic disciplines in order to achieve a more comprehensive and in-depth understanding of complex phenomena and problems. Unlike single-disciplinary approaches, which examine objects of study within a

limited perspective, interdisciplinarity seeks the synthesis and mutual enrichment of diverse viewpoints (Repko & Szostak, 2021).

The essence of the interdisciplinary approach lies not merely in the mechanical combination of knowledge, but in the creation of new, integrative understanding that transcends the boundaries of individual disciplines. In this sense, it involves active interaction among different fields of study, as well as the ability to overcome conceptual differences and establish a shared language (Klein, 2010).

The main characteristics of the interdisciplinary approach can be outlined as follows:

- **Integrativity** – the integration of theories, methods, and concepts from different disciplines into a unified analytical framework;
- **Complexity** – a focus on the study of multilayered and interconnected problems;
- **Systemicity** – viewing phenomena as part of broader systems and networks of interactions;
- **Contextuality** – taking into account the social, cultural, and organizational context;
- **Creativity and innovation** – generating new solutions through the combination of diverse perspectives;
- **Dialogicity** – interaction and exchange between different scientific traditions and approaches.

Interdisciplinarity is closely linked to the need to address complex, real-world problems that cannot be solved within the boundaries of a single discipline. In this sense, it has not only theoretical but also strong practical significance, particularly in fields such as education, management, and leadership (Frodeman, 2017).

In the context of leadership education, the interdisciplinary approach enables the integration of knowledge from psychology, pedagogy, sociology, management, and other fields. This facilitates the development of more holistic and adaptive leadership competencies, aligned with the complexity of the contemporary environment.

In conclusion, the interdisciplinary approach can be regarded as a key paradigm of contemporary knowledge, reflecting the transition from a fragmented to a holistic understanding of reality and providing a foundation for more effective education and practice in the field of leadership.

Distinction: Multidisciplinarity, Interdisciplinarity, Transdisciplinarity

In contemporary scientific and educational practice, the concepts of multidisciplinarity, interdisciplinarity, and transdisciplinarity are frequently used to denote different levels of integration among academic disciplines. Despite their similarities, these approaches differ significantly in terms of the degree of interaction, synthesis, and purpose.

Multidisciplinarity refers to the parallel use of knowledge from different disciplines, which, however, retain their autonomy. Within this approach, each discipline examines a given problem from its own perspective, without deep integration among them. The result is the coexistence of multiple viewpoints that contribute to a broader, though not necessarily synthesized, understanding (Klein, 2010).

Interdisciplinarity, in contrast, involves active interaction and integration among disciplines. It includes the exchange of concepts, methods, and theoretical frameworks, leading to the creation of new, synthesized knowledge. The interdisciplinary approach aims not merely at joint consideration, but at mutual enrichment and the transcendence of disciplinary boundaries (Repko & Szostak, 2021).

Transdisciplinarity represents the highest level of integration, where not only the boundaries between disciplines are transcended, but also those between science and practice. This approach involves the participation of various stakeholders (e.g., practitioners, organizations, communities) and is oriented toward solving real, complex problems through the co-creation of

knowledge (Frodeman, 2017). Transdisciplinarity is characterized by holism and a focus on sustainable solutions.

In the context of leadership education, these three approaches offer different opportunities. Multidisciplinarity broadens the cognitive horizon, interdisciplinarity fosters integrative thinking, and transdisciplinarity prepares future leaders for real, complex situations by linking theory and practice.

Benefits of Knowledge Integration

The integration of knowledge from different disciplinary fields represents a core element of the interdisciplinary approach and plays a key role in enhancing the quality and effectiveness of leadership education. In conditions of increasing complexity and interconnectedness, the ability to synthesize diverse perspectives becomes a strategic advantage for both individuals and organizations.

One of the main benefits of knowledge integration is a **deeper and more comprehensive understanding of complex phenomena**. The combination of different theoretical frameworks and methodological approaches allows problems to be analyzed from multiple perspectives, reducing the risk of one-sided interpretations (Repko & Szostak, 2021).

A second important benefit is the **stimulation of critical and systems thinking**. When learners are exposed to diverse concepts and approaches, they develop skills for comparison, evaluation, and synthesis of information. This supports their ability to operate effectively in complex and uncertain situations (Klein, 2010).

Knowledge integration also fosters **innovation and creativity**. The interaction between different disciplines creates conditions for generating new ideas and unconventional solutions, as significant breakthroughs often emerge at the intersections of fields (Johansson, 2017).

Another important benefit is the enhancement of **adaptability and flexibility** among future leaders. Through interdisciplinary education, they develop the ability to navigate diverse contexts, adjust their approaches, and respond effectively to rapidly changing environments (Northouse, 2022).

Furthermore, knowledge integration supports the **connection between theory and practice** by enabling the application of theoretical concepts in real-world situations. This makes education more relevant and effective, particularly in fields such as leadership, where practical skills are essential (Frodeman, 2017).

Last but not least, this approach contributes to the development of a **holistic perspective**, where phenomena are viewed as part of broader systems. This is especially important for leaders who must make decisions with long-term and multidimensional consequences.

In summary, knowledge integration creates the conditions for developing complex, adaptive, and innovative leadership competencies. It not only broadens cognitive horizons but also supports the development of skills necessary for effective action in today's interconnected world.

Limitations and Challenges of the Interdisciplinary Approach

Despite its undeniable advantages, the application of the interdisciplinary approach in leadership education is associated with a number of limitations and challenges that require careful analysis and targeted efforts to overcome.

One of the main challenges is the **conceptual and methodological complexity** of interdisciplinarity. Integrating different theoretical frameworks and research methods often leads to difficulties in establishing coherence and a shared logic. Different disciplines employ specific terminologies and approaches, which can hinder communication and mutual understanding (Klein, 2010).

Another significant issue is the **lack of sufficient preparation and competence among educators** to work in an interdisciplinary environment. The effective implementation of this approach requires not only deep expertise in a particular field, but also the ability to engage with

multiple disciplinary perspectives—something that is not always part of traditional academic training (Repko & Szostak, 2021).

There are also **institutional barriers** related to the structure of educational systems, which are often organized along disciplinary lines. Curricula, assessment methods, and academic standards are not always aligned with interdisciplinary forms of learning, making their implementation more difficult (Frodeman, 2017).

An additional challenge concerns the **assessment of learning outcomes**. Interdisciplinary competencies, such as systems thinking, creativity, and the ability to synthesize knowledge, are more difficult to measure using traditional evaluation methods. This raises the need for developing new criteria and assessment tools.

Another important aspect is the **risk of superficiality and loss of depth**. If integration is not well balanced, there is a danger that learning may remain at the level of general ideas without a deep understanding of individual disciplines. This may compromise the overall quality of knowledge.

Furthermore, the interdisciplinary approach requires **more time, resources, and coordination**, which can be challenging in contexts of limited institutional capacity. The organization of joint courses, team teaching, and integrated projects demands a high level of collaboration among educators and institutions.

Despite these limitations, most scholars emphasize that the challenges of interdisciplinarity do not diminish its importance; rather, they highlight the need for the purposeful development of new pedagogical strategies, institutional models, and research practices.

In conclusion, the successful implementation of the interdisciplinary approach in leadership education requires a balance between integration and depth, as well as the creation of an appropriate educational and organizational environment that supports this process.

Interdisciplinarity in Leadership Education

The interdisciplinary approach in leadership education is implemented through the integration of knowledge and practices from various academic fields, each contributing specific concepts and tools for the development of complex leadership competencies. Among the key disciplines of particular importance are psychology, pedagogy, sociology, and management.

Psychology provides the foundation for understanding individual behavior, motivation, and emotional processes. The concept of emotional intelligence highlights the importance of self-awareness, self-regulation, empathy, and social skills as key components of effective leadership (Goleman, 1998). In addition, motivational theories (e.g., self-determination theory) explain how leaders can foster engagement and intrinsic motivation among their followers (Deci & Ryan, 2000).

Pedagogy contributes methods and approaches for effective learning and the development of leadership skills. Emphasis is placed on active and experiential methods such as project-based learning, case studies, and reflective practices, which support learning through experience (Kolb, 1984). Communication as a pedagogical process also plays a crucial role in building trust, sharing knowledge, and developing leadership potential.

Sociology provides insight into social structures, group dynamics, and cultural differences. Leadership is viewed as a socially constructed process that emerges through interactions among individuals. Understanding group processes, roles, and norms supports leaders in managing teams and creating effective organizational cultures (Giddens, 2009).

Management complements this interdisciplinary framework by providing strategies, models, and tools for managing organizations. Concepts such as organizational behavior, strategic thinking, and change management are essential for the practical application of leadership in real organizational contexts (Mintzberg, 2009).

The integration of these fields creates the possibility for a **holistic approach to leadership education**, in which individual, social, and organizational dimensions are considered in their interrelations. This enables the development of leaders who not only possess knowledge but are also capable of applying it in complex, dynamic, and multilayered situations.

In conclusion, the connections between psychology, pedagogy, sociology, and management form both a theoretical and practical foundation for interdisciplinary leadership education, aligned with the demands of the contemporary interconnected world.

The Role of Holistic Thinking

In the context of the interdisciplinary approach to leadership education, holistic thinking emerges as a key cognitive and practical competence. It involves perceiving phenomena as part of integrated systems in which individual elements are interconnected and interdependent. Unlike the reductionist approach, which analyzes components in isolation, holistic thinking seeks to understand the overall picture and the dynamics of interactions.

One of the primary functions of holistic thinking is to support the **systemic understanding of complex processes**. Leaders who possess this capability are able to identify interconnections, dependencies, and the long-term consequences of their decisions. This is particularly important in dynamic and interconnected environments, where changes in one part of the system can affect the whole (Senge, 2006).

Holistic thinking also plays a significant role in **effective decision-making**. By integrating diverse perspectives and types of knowledge, leaders can formulate more balanced and sustainable decisions that take into account both short-term and long-term effects (Stermann, 2000).

Another important characteristic is the connection between **holistic thinking and interdisciplinarity**. The ability to make connections across different domains of knowledge forms the foundation of the integrative approach that lies at the core of contemporary leadership education. Holistic thinking helps overcome the fragmentation of knowledge and creates conditions for the synthesis of ideas and concepts (Klein, 2010).

Furthermore, holistic thinking contributes to the development of **adaptability and flexibility**, as it enables leaders to respond effectively to changing conditions and to operate in environments of uncertainty. It encourages openness to new perspectives and a readiness to learn, which are essential in today's context.

From a pedagogical perspective, the development of holistic thinking requires the application of **active and interdisciplinary learning methods** that stimulate analysis, synthesis, and reflection. This includes working with real-life cases, project-based learning, and collaboration across different fields of knowledge.

In conclusion, holistic thinking is a fundamental element of contemporary leadership and a key prerequisite for the effective application of the interdisciplinary approach. It enables leaders to understand the complexity of the world in its entirety and to act in ways that are adaptive, responsible, and sustainable.

Development of Complex Leadership Competencies

In conditions of increasing complexity, dynamism, and interconnectedness of social and organizational systems, contemporary leadership education requires the development of complex leadership competencies that go beyond traditional managerial skills. These competencies integrate cognitive, emotional, social, and strategic capabilities necessary for effective functioning in a multilayered and evolving environment.

First, the development of systems thinking is of crucial importance, as it allows leaders to understand the interrelationships between different elements of a system and to anticipate the

consequences of their decisions (Senge, 2006). This skill is closely linked to the holistic approach and forms the foundation for managing complex processes effectively.

A second important group of competencies relates to emotional intelligence, including self-awareness, self-regulation, empathy, and relationship management skills. These abilities support trust-building, effective communication, and the engagement of followers (Goleman, 1998).

Contemporary leadership also requires a high level of adaptability and flexibility, enabling leaders to respond effectively to change, uncertainty, and unpredictable situations. The concept of adaptive leadership highlights the importance of learning, experimentation, and the capacity to address complex challenges (Heifetz, Grashow, & Linsky, 2009).

Equally important is **intercultural competence**, which is gaining increasing significance in a globalized environment. Leaders must understand and respect cultural differences, communicate effectively within multicultural teams, and foster an inclusive organizational culture (Mendenhall et al., 2017).

The interdisciplinary approach also contributes to the development of **critical and creative thinking**, which are essential for analyzing complex problems and generating innovative solutions. The ability to integrate diverse perspectives supports the creation of sustainable and effective strategies (Johansson, 2017).

Furthermore, contemporary leaders must possess strong **communication and collaboration skills**, enabling effective interaction within teams and networks. Leadership is increasingly realized as a process of co-creating meaning and coordinating collective action (Uhl-Bien, 2006).

From a pedagogical perspective, the development of these competencies requires the application of **active, experiential, and interdisciplinary learning methods**, which create conditions for the practical application of knowledge and reflection on experience.

In conclusion, complex leadership competencies represent an integrative outcome of the interaction between different domains of knowledge and practice. Their development is a key condition for preparing leaders capable of acting effectively in today's interconnected world.

Conclusion

This paper examined leadership education in the context of the contemporary interconnected world, characterized by high dynamism, complexity, and nonlinearity of processes. The analysis demonstrated that traditional, single-disciplinary models of education are insufficient to meet the demands of modern reality, in which leadership is manifested as a relational, context-dependent, and systemic process.

The main characteristics of the interdisciplinary approach were outlined, including its integrative nature, its orientation toward complex problems, and its capacity to synthesize knowledge from diverse fields. The distinction between multidisciplinary, interdisciplinarity, and transdisciplinarity highlighted different levels of interaction, with interdisciplinarity emerging as a particularly suitable framework for leadership education.

The paper emphasized the importance of connections between key academic disciplines—psychology, pedagogy, sociology, and management—which together contribute to the development of a holistic understanding of leadership. Particular attention was also given to the role of holistic thinking and the development of complex leadership competencies, including systems thinking, emotional intelligence, adaptability, and the ability to operate in networked environments.

The analysis of the benefits and limitations of the interdisciplinary approach showed that, despite existing challenges, its implementation is essential for enhancing the effectiveness and relevance of leadership education.

In this context, it can be firmly concluded that the interdisciplinary approach is not merely an alternative, but a necessity in contemporary leadership education. It provides the conditions for overcoming the fragmentation of knowledge, fosters critical and systems thinking, and supports the development of leaders capable of acting effectively in a complex, interconnected, and rapidly changing environment.

Interdisciplinarity not only expands the boundaries of knowledge but also transforms the very nature of leadership—from a static role into a dynamic process of connecting, understanding, and creating meaning in a complex and interdependent world.

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Medical Sciences

Addressing Healthcare Accessibility and Efficiency Challenges in Georgia's Mountainous Regions: A Comparative Review of Imereti and Adjara

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Abstract

Mountainous regions, as geographically isolated and structurally vulnerable spaces, present a highly complex context for ensuring equitable health outcomes. In Georgia, these regions are characterized by limited physical access to medical services, acute personnel shortages, and uneven infrastructural development, which directly impacts the population's health status.

This paper evaluates the systemic barriers within the healthcare sectors of Imereti and Adjara and analyzes strategic opportunities for improvement. The study employs a mixed-methods approach, integrating quantitative indicators with qualitative insights.

The research focuses on three pivotal dimensions:

1. Health Literacy: Examining public awareness levels and their influence on the rational utilization of services.
2. Technological Integration: Assessing the potential of telemedicine and digital platforms to bridge geographical gaps.
3. Preventive Strategies: Evaluating the role of primary healthcare in early diagnosis and the optimization of systemic costs.

The paper introduces the Highland Health Resilience Model (HHRM), which integrates digital innovation and health literacy as primary drivers for systemic transformation. The research demonstrates that incorporating prevention-oriented approaches significantly reduces the rate of avoidable hospitalizations and optimizes limited medical resources. This model establishes a robust framework for implementing person-centered management, which is critical for overcoming barriers imposed by geographical isolation. From an economic perspective, the implementation of the HHRM facilitates the reduction of transactional costs and enhances the financial sustainability of the regional healthcare system.

The paper concludes with evidence-based recommendations for policymakers aimed at reducing regional health inequalities and enhancing system resilience, in direct alignment with UN Sustainable Development Goals (SDG 3, 4, and 10).

Keywords: *Mountainous regions, healthcare accessibility, telemedicine, health literacy, preventive medicine, health equity.*

Introduction

Against the backdrop of contemporary global challenges, ensuring Health Security has become a paramount priority. This process is particularly complex and multifaceted in mountainous regions, which, due to their natural, geographical, and socio-economic characteristics, differ significantly from lowland and urban centers. In Georgia, where a substantial portion of the territory consists of mountainous zones, the issue of equitable access to healthcare services remains a pressing structural challenge.

The cases of the mountainous municipalities in Imereti and Adjara clearly demonstrate that traditional approaches, focused solely on infrastructural development, are often insufficient for achieving sustainable outcomes. Geographical isolation, seasonal climatic conditions (such as heavy snowfall and landslide processes in Adjara), and medical personnel shortages create barriers that require not only physical investment but also a transformation of operational models.

In this context, health security is no longer viewed merely as the existence of medical facilities. It is closely linked to the population's Health Literacy—the ability to correctly perceive medical information and make preventive decisions. Simultaneously, the integration of digital technologies and telemedicine elements represents the essential bridge intended to reduce the distance between the patient and qualified medical services.

Within the scope of this research, particular attention is paid to the structure of healthcare utilization. In the mountainous settlements of Imereti and Adjara, a trend is emerging where the use of medical services often bears a reactive rather than proactive (preventive) character.

This paper discusses the key factors influencing the resilience of the healthcare system in mountainous regions. The study analyzes the role of the primary healthcare sector and the importance of preventive medicine as the main strategy for resource optimization and improving population well-being. The objective of this work is to formulate practical recommendations that will assist policymakers and medical professionals in creating more effective, person-centered regional healthcare models.

Research Methodology

The present study is based on a Mixed-Methods Research approach, which allows for the analysis of the problem through both quantitative data and qualitative contextual frameworks. The research design includes the following components:

1. Systematic Literature Review and Document Analysis:

- Study of international experiences regarding healthcare management in mountainous regions (European and Asian models).
- Analysis of data from the Ministry of Health of Georgia and the National Statistics Office of Georgia (Geostat) for the Imereti and Adjara regions.

2. Comparative Regional Analysis (Comparative Case Study):

- The mountainous municipalities of Imereti and Adjara have been selected as the research subjects.
- The analysis focuses on two main parameters:
 - **Physical Accessibility:** The distance from residential areas to the nearest medical point and transportation time.
 - **Service Utilization:** The ratio of scheduled vs. emergency visits; rates of avoidable hospitalizations.

3. Qualitative Research – Expert Assessments:

- In-depth interviews with medical personnel (family physicians, nurses) directly working in mountainous zones.
- Study of their experiences regarding patients' health literacy and their readiness to utilize technology.
- Key Informant Interviews to identify systemic barriers.

Variables and Operationalization

The study is based on three primary Independent Variables:

1. Health Literacy
2. Technological Accessibility and Utilization
3. Preventive Behaviors

Dependent Variables include:

- Health outcomes (self-reported health status)
- Efficiency of service utilization
- Avoidable hospitalizations

Control Variables include:

- Age, Gender
- Socio-economic status
- Geographical accessibility

Data Analysis

Quantitative data will be processed using statistical software (e.g., SPSS/Stata), including:

- Descriptive statistics
- Correlation analysis
- Multivariate **regression models** to identify significant predictors.

Qualitative data will be analyzed using Thematic Analysis, allowing for the identification of key narratives and systemic barriers. Methodological integration will be achieved through the principle of Triangulation, which enhances the reliability and validity of the research.

4. Ethical Considerations

The research is conducted in strict adherence to the principles of bioethics. The confidentiality of participants and the anonymity of data are fully ensured throughout the study process.

Research Limitations

The potential limitations of this study include:

- Self-report bias: Potential biases associated with the use of self-reported data by participants.
- Heterogeneity of mountainous regions: Differences between various highland areas may complicate the universal generalization of the results.
- Infrastructure dependency: Dependence on digital infrastructure during the data collection process.

Connection Between Methodology and Analytical Framework

The selected methodological approach ensures the testing of hypotheses defined within the analytical framework and establishes an evidence-based foundation for evaluating the integrated model and its application at the policy level.

Indicator Framework (Narrative)

The research comprises three core components, the results of which are evaluated through specific indicators:

Component 1: Health Literacy Engine

Health literacy is assessed using a Health Literacy Index, providing a realistic, quantitative narrative of the increase in public knowledge and awareness. Additionally, for stakeholders, the Digital Resource Utilization Rate is considered, reflecting public access to online health education and mHealth platforms. Another key indicator is the Participation Rate in Preventive Programs, which allows for an assessment of community involvement in forming active, long-term healthy behaviors.

Component 2: Digital Access Layer

Technological interventions are evaluated by the number of telemedicine consultations per 1,000 residents, reflecting service accessibility in isolated regions. Furthermore, the use of Remote Diagnostics is assessed as a quality-oriented indicator, demonstrating the impact of technological access on the timeliness of diagnosis. Another crucial factor is the reduction in service access time, reflecting improvements in the efficiency of healthcare availability.

Component 3: Preventive Care Core

Preventive medicine is evaluated through screening coverage within target groups, serving as a direct measure of the prevalence and effectiveness of preventive interventions. A vital indicator of systemic efficiency is the reduction in avoidable hospitalizations, highlighting the role of primary healthcare. Additionally, the early detection of chronic diseases is noted as an outcome directly linked to increased health literacy and the integration of preventive behaviors.

Main Body: Analysis of the Healthcare Ecosystem in Mountainous Regions

1. Structural and Geographical Determinants

An analysis of mountainous settlements in **Imereti and Adjara** reveals that the geographical landscape directly impacts the efficiency of medical services. Natural barriers (terrain, climate) create a so-called **"time deficit"** in critical situations. The research highlights that the mere existence of physical infrastructure (buildings) does not solve the problem if there is no well-functioning logistical and communication chain between medical personnel and the local population.

2. Human Resource Management and the Work Environment

In mountainous regions, the shortage of medical personnel and their workload is at a critical threshold. Managerial flaws, such as improper work schedule planning or communication dissonance between administration and staff, directly affect patient satisfaction. To prevent personnel burnout, it is essential to optimize work processes and utilize digital tools to alleviate the administrative burden.

3. Health Literacy and Patient Behavior

One of the primary findings of this study is the correlation between public awareness and the quality of healthcare utilization. Low health literacy leads patients to ignore early symptoms, which ultimately results in the irrational loading of emergency services. The integration of preventive medicine through educational programs (especially among the youth) serves as a guarantee for the resilience of the system.

4. Technological Readiness and the Digital Divide

While telemedicine is viewed as a solution, in reality, we encounter a „digital divide“- the gap between technological capabilities and the population's ability to use these services. The examples of Adjara and Imereti demonstrate that the implementation of digital instruments must be preceded by appropriate training for both the population and medical staff.

Positioning within the Literature and Innovation

Existing healthcare models typically focus on individual components-for instance, strengthening primary healthcare or implementing digital technologies. While these approaches are effective in

specific aspects, they often fail to achieve systemic transformation, as they do not account for the integrated impact of behavioral and educational factors.

In this context, the primary innovation of the HHRM (Highland Health Resilience Model) lies in its integrative nature. Unlike traditional Primary Health Care (PHC) models, which are mainly oriented toward service delivery, or digital health models, which concentrate on technological solutions, the HHRM unites both directions. Furthermore, it incorporates a third, often overlooked component: Health Literacy, as a systemic driver.

This integration creates added value not only at a theoretical level but also in practice. It ensures the model's adaptability across various contexts and increases the likelihood of its successful implementation.

Policy Implications: From Model to Action

One of the primary strengths of the HHRM is its direct translatability into policy instruments. The model provides a clear framework for planning both short-term and long-term interventions.

In the short term, the most immediate steps include expanding telemedicine services and integrating digital platforms into the primary healthcare network, providing improved access at a relatively low cost. In the medium term, the institutionalization of health literacy programs is critical, particularly through the educational system and community-based initiatives. In the long term, systemic reforms are required, including the reorientation of funding models toward prevention, which will ensure the financial sustainability of the healthcare system.

This phased approach increases the feasibility of policy implementation and reduces the risk of reform failure.

Economic and Systemic Impact

Research findings indicate that the HHRM holds significant potential for improving the economic efficiency of the healthcare system. Strengthening preventive approaches and increasing health literacy reduces avoidable hospitalizations, which represent one of the most substantial cost components in healthcare.

Furthermore, technological interventions reduce transactional costs (transportation costs, time expenditure) and increase the efficiency of service delivery. Consequently, resources are reallocated from high-cost reactive services (hospital-based care) to more efficient, preventive, and primary healthcare services.

This economic logic is particularly vital for policymakers, as it demonstrates that the model not only improves health outcomes but also reduces systemic costs in the medium and long term.

Integration within the SDG Context

The HHRM serves as a practical tool for achieving global development goals. The model directly contributes to the fulfillment of Sustainable Development Goal 3 (Good Health and Well-being) by improving health outcomes, while its focus on health literacy reinforces SDG 4 (Quality Education). Simultaneously, technological interventions reduce geographical inequalities, facilitating the attainment of SDG 10 (Reduced Inequalities). It is crucial to note that this connection is not merely declarative; it is based on specific mechanisms described within the model's framework, which can be evaluated using defined indicators.

Implementation Considerations: Barriers and Opportunities

Despite the model's potential, its effective implementation depends on several critical factors. One of the primary barriers is the digital divide, which may limit the impact of technological interventions. Equally important is the readiness and skill set of medical personnel to utilize new digital instruments.

Limited financial resources and policy instability pose additional challenges, particularly in countries in transition. However, significant opportunities exist—including support from international donors, the rapid advancement of digital technologies, and the increasing

engagement of local communities. Accounting for these factors is critical for the model's successful implementation and must be integrated into the policy-planning process.

Limitations

Despite the comprehensive design of this research, certain limitations must be acknowledged. The study is contextually tied to the mountainous regions of Georgia, which may limit the direct generalizability of the findings to other countries. Furthermore, a portion of the data utilized is based on self-reported assessments, which increases the risk of subjective bias.

Additionally, the proposed model requires further empirical testing across diverse contexts to fully evaluate its effectiveness and replicability.

Conclusion

The research confirms that in mountainous regions (Imereti and Adjara), the quality of health security is directly linked not only to medical infrastructure but also to public awareness and the flexibility of managerial processes. The identified problem of "delayed healthcare seeking" underscores the urgent need to strengthen preventive mechanisms. Furthermore, technological interventions will only be effective if accompanied by an increase in digital literacy among both patients and medical personnel.

Ultimately, the study demonstrates that ensuring health security in highland regions cannot be achieved through infrastructural investments alone. The HHRM offers an alternative, integrated approach where education, technology, and prevention function as a unified system to create a stable, resilient, and equitable healthcare environment.

The research emphasizes that the synergy created between these three components results in a resilient, efficient, and economically sustainable healthcare system that directly aligns with global priorities (SDG 3, SDG 4, and SDG 10).

Recommendations

Based on the research findings, the following recommendations have been developed:

1. **Implementation of Health Literacy Programs:** It is advisable to launch educational campaigns at the regional level focused on early disease symptomatology and the vital importance of prevention.
2. **Digital Support for Primary Healthcare:** Active integration of telemedicine elements into the daily activities of family physicians and nurses is essential to reduce the impact of physical barriers in the diagnostic process.
3. **Human Resource Optimization:** Improving the management of medical personnel's work schedules and administrative workloads to prevent systemic delays and enhance service quality.
4. **Multisectoral Collaboration:** Coordinated action among local self-governments, educational institutions, and medical centers within a unified health security strategy.

Ultimately, the effectiveness of the healthcare system in mountainous regions depends not only on technical equipment but also on the existence of person-centered management. This ensures continuous communication, rational utilization of local medical personnel, and seamless access to services-representing the sole prerequisite for the sustainable development of regional healthcare.

Анатомо-клинические особенности поражения верхнего ствола плечевого сплетения (C5–C6) у детей с параличом Эрба-Дюшенна

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Введение:

Поражение верхнего ствола плечевого сплетения (C5–C6), известное как паралич Эрба–Дюшенна, является наиболее частой акушерской травмой периферической нервной системы у новорожденных — 1–4 случая на 1000 живорождений, из которых 90% составляют верхние поражения.[1,2] Возникает вследствие тракционного повреждения корешков C5–C6 при осложненных родах (дистоция плеча, макросомия), что нарушает иннервацию проксимальных мышц плечевого пояса (дельтовидная, надостная, подостная, бицепс brachii) и формирует характерную позу «официанта, оставляющего чаевые» — висячую руку с внутренней ротацией плеча и пронацией предплечья.[1,3] Механизм повреждения включает растяжение нервных волокон от нейропраксии (спонтанное восстановление в 70–90% случаев) до аксонотомезиса/нейротомезиса с разрывом стволов; среди факторов риска — крупный плод (>4000 г), узкий таз матери и акушерские манипуляции.[4,5] Клиническая картина: отсутствие abduction/внешней ротации плеча, сгибания локтя, супинации предплечья при сохранении функций кисти и пальцев (дифференциальный признак от тотального плечеплексита); рефлексы снижены, чувствительность сохранена [1,3,6]. В тяжелых случаях формируются контрактуры (локтевой/плечевой) и glenohumeral dysplasia, требующие хирургии [7,8]. Диагностика включает клинический осмотр (шкала Active Movement Scale — AMS), электромиографию (ЭНМГ с 3-й недели), УЗИ и МРТ-нейровизуализацию для определения пре-/постганглионарного уровня поражения [9,10]. Ранняя верификация (1–3 мес.) критически важна для прогнозирования и выбора тактики [9,10]. Актуальность обусловлена сохраняющейся частотой патологии (3/1000) и риском стойкого дефицита в 20–30% случаев при поздней диагностике, несмотря на прогресс акушерства [2,5].

1. Структурно-функциональные особенности плечевого сплетения

1.1 Морфология плечевого сплетения

Плечевое сплетение (plexus brachialis) формируется из передних ветвей четырех нижних шейных спинномозговых нервов и анатомически подразделяется на надключичную и подключичную части [11].

Надключичная часть образует 3 ствола: верхний (superior trunk), средний (middle trunk) и нижний (inferior trunk). Подключичная часть включает 3 пучка (cords): латеральный, задний и медиальный. [11].

Топография верхнего ствола (C5–C6): образуется слиянием C5 и C6 в заднем треугольнике шеи между передней и средней лестничными мышцами. Ствол проходит латерально над верхушкой лёгкого и первым ребром, его длина в надключичной части относительно короткая (примерно 2–3 см до деления на ветви, что делает его уязвимым при тракции).

Верхний ствол (C5–C6) формирует короткие и длинные ветви, которые обеспечивают иннервацию проксимальных мышц плеча и всей свободной части верхней конечности [11]. К коротким ветвям относятся дорсальный нерв лопатки, длинный грудной, подключичный, надлопаточный, подлопаточный, грудоспинной, латеральный и медиальный грудные нервы, а также подмышечный нерв [11].

Таблица 1

Нерв	Уровень происхождения	Иннервируемые мышцы	Функция
Дорсальный нерв лопатки	Корни (C5)	m. rhomboideus major et minor, m. levator scapulae	Аддукция (приведение) и стабилизация лопатки, опускание лопатки
Длинный грудной нерв	Корни (C5–C7)	m. serratus anterior	Пронация и ротация лопатки вверх/вперёд (обеспечивает абдукцию плеча >90°, фиксация лопатки к грудной клетке)
Нерв к подключичной мышце	Верхний ствол (C5–C6)	m. subclavius	Депрессия (опускание) ключицы, стабилизация плечевого пояса
Надлопаточный нерв	Верхний ствол (C5–C6)	m. supraspinatus, m. infraspinatus	Инициация абдукции плеча (первые 0–30°), наружная ротация плеча
Верхний подлопаточный нерв	Задний пучок	m. subscapularis (верхняя часть)	Внутренняя ротация плеча
Нижний подлопаточный нерв	Задний пучок	m. subscapularis (нижняя часть), m. teres major	Внутренняя ротация плеча, аддукция плеча
Грудоспинной нерв	Задний пучок (C6–C8)	m. latissimus dorsi	Аддукция, разгибание и внутренняя ротация плеча
Латеральный грудной нерв	Латеральный пучок (C5–C7)	m. pectoralis major (ключичная часть)	Сгибание, приведение и внутренняя ротация плеча
Медиальный грудной нерв	Медиальный пучок (C8–T1)	m. pectoralis minor, m. pectoralis major (стернокостальная часть)	Приведение плеча, депрессия лопатки, стабилизация
Подмышечный нерв	Задний пучок (C5–C6)	m. deltoideus, m. teres minor	Абдукция плеча (основная — дельтовидная), наружная ротация (teres minor)

Источник: Okwumabua E., Black A.C., Thompson J.H. Anatomy, Shoulder and Upper Limb, Nerves. StatPearls Publishing, 2026. [12]

Длинные ветви верхнего ствола представлены мышечно-кожным, медиальным и срединным, локтевым и лучевым нервами [11].

Таблица 2

Нерв	Уровень происхождения	Иннервируемые мышцы	Функция
Мышечно-кожный нерв	Латеральный пучок	m.coracobrachialis, m. biceps brachii, m. brachialis	Сгибание локтя, супинация предплечья; кожа латеральной поверхности предплечья
Срединный нерв	Латеральный + медиальный пучки	Передние мышцы предплечья (flexors), мышцы тенара (thenar), lumbricals 1–2	Сгибание запястья/пальцев, противопоставление большого пальца; кожа ладонной поверхности I–III пальцев и половины IV
Локтевой нерв	Медиальный пучок	m. flexor carpi ulnaris, медиальная часть глубокого сгибателя пальцев, гипотенар, interossei, lumbricals 3–4	Сгибание запястья (локтевое), отведение/приведение пальцев, сгибание дистальных фаланг IV–V; кожа медиальной поверхности кисти и IV–V пальцев
Лучевой нерв	Задний пучок	m. triceps brachii, m. brachioradialis, разгибатели предплечья/кисти/пальцев	Разгибание локтя, запястья, пальцев; супинация; кожа задней поверхности плеча, предплечья и тыльной стороны I–III пальцев
Подмышечный нерв	Задний пучок	m. deltoideus, m. teres minor	Абдукция плеча (дельтовидная), наружная ротация плеча; кожа верхнелатеральной поверхности плеч

Источник: Jones O. The Brachial Plexus – Sections, Branches. TeachMeAnatomy, 2025 [13]

1.2. Функциональная анатомия

Верхний ствол C5–C6 обеспечивает ключевые движения верхней конечности:

- Абдукцию плеча — m. supraspinatus + m. deltoideus .
- Наружную ротацию — m. infraspinatus + m. teres minor.
- Сгибание локтя — m. biceps brachii + m. brachialis.

При поражении верхнего ствола формируется классическая «поза официанта» (waiter's tip): рука приведена и ротирована внутрь, локоть разогнут, предплечье пронировано. У новорождённых это проявляется отсутствием рефлекса Моро на поражённой стороне и сохранностью хватательного рефлекса. [13]

Возрастные особенности: у плодов и новорождённых нервные структуры обладают особой биомеханикой — меньшей эластичностью по сравнению со взрослыми, что делает их более уязвимыми к тракционному повреждению. Однако регенеративный потенциал выше: в 80–90 % случаев возможно спонтанное восстановление в течение первого года жизни при своевременной диагностике[1]

1.3. Анатомические предпосылки травмы

Ключевой анатомической предпосылкой травмы верхнего ствола плечевого сплетения у новорождённых является тесная топографическая связь корешков C5–C6 с шейными позвонками. Корешки выходят непосредственно через межпозвонковые отверстия шейных позвонков и формируют плечевое сплетение в области шеи и надключичной зоны, что делает их крайне уязвимыми к тракционным и ротационным силам во время родов.[15]

В исследовании da Cunha MR и соавт. (2020) на 9 формалин-фиксированных плодах человека (12–30 недель гестации) показано, что в раннем периоде (до 20 недель) плечевое сплетение имеет вид единого тяжа, проходящего через hiatus между передней и средней лестничными мышцами; только после 28 недель морфология и синтопия приближаются к взрослым. Авторы подчёркивают, что «топографическое расположение сплетения делает его восприимчивым к травме из-за близости к колеблющимся структурам шеи и плеча, а также отсутствия мышечной и костной защиты».[15] Травма возникает при чрезмерной тракции головки плода на фоне дистонии плеча, что приводит к растяжению или авульсии корешков C5–C6.[16]

Анатомия шейного отдела позвоночника и смежных структур у плода/новорождённого радикально отличается от взрослой, что значительно повышает риск повреждения даже при минимальных механических воздействиях.[16,17] Основные различия включают:

- непропорционально крупную голову и краниально смещённый центр тяжести при слабом развитии шейных мышц, создающие высокий момент силы при тракции;[16]
- расположение фулькрума движения на уровне C2–C3 (у взрослых — C5–C6);[17]
- более горизонтальную ориентацию фасеток суставов, гиперэластичные связки и диски;[17]
- клиновидную форму тел позвонков, множественные синхондрозы (C1, C2) и высокую растяжимость шейного отдела (до 5 см без костной травмы при растяжении спинного мозга всего на 0,6 см — феномен SCIWORA).[16,17]

Таким образом, анатомическая близость верхнего ствола плечевого сплетения и спинного мозга к шейным позвонкам в сочетании с незрелостью структур у плода (по сравнению со взрослым) создаёт уникальную предрасположенность к тракционному повреждению C5–C6 при минимальной силе во время родов. Эти данные, подтверждённые зарубежными морфологическими, биомеханическими и клиническими исследованиями, имеют прямое значение для понимания патогенеза паралича Эрба–Дюшенна и выбора тактики ранней диагностики.

2.2 Классификация повреждений (Сэддон, Sunderland)

Повреждения плечевого сплетения классифицируются по степени тяжести и глубине структурных нарушений, что имеет решающее значение для прогноза и выбора тактики лечения. Наиболее широко используются две взаимодополняющие системы — Седдона (1943) и Сандерланда (1951).[19,20]

Таблица 3. Классификация повреждений периферических нервов по Седдону(1943)

Тип повреждения	Степень	Патогенетический механизм и структурные изменения
Нейропраксия	I	Лёгкое растяжение с обратимым блоком проведения импульса; демиелинизация без нарушения целостности аксонов и оболочек
Аксонотмезис	II	Разрыв аксонов при сохранности эндоневрия; Валлерова дегенерация дистально
Нейротмезис	III	Полный разрыв нерва или авульсия корешка; нарушение всех оболочек

Таблица 4. Классификация повреждений периферических нервов по Сандерланду(1951)

Степень	Патогенетический механизм (повреждённые структуры)
I	Повреждение только миелина (локальный блок проведения) Аксон, эндоневрий, периневрий, эпиневрй
II	Разрыв аксонов и миелина; эндоневрий сохранён
III	Разрыв аксонов, миелина и эндоневрия; периневрий сохранён
IV	Разрыв аксонов, миелина, эндоневрия и периневрия; эпиневрй цел
V	Полный перерыв нерва (все структуры, включая эпиневрй)

При параличе Эрба–Дюшенна преобладают лёгкие формы (Седдон I / Сандерланд I–II) — до 70–80 % случаев, с полным спонтанным восстановлением к 3–6 месяцам. Тяжёлые повреждения (Сандерланд III–V) встречаются в 20–30 % и приводят к стойкому дефициту, контрактурам и дисплазии плечевого сустава. Наракская классификация дополнительно учитывает клинический объём поражения (группы 1–4), что позволяет прогнозировать исход уже на 2–3-й неделе жизни.[20]

3. Клиническая картина

3.1 Типичная поза официанта

Поражение верхнего ствола плечевого сплетения (C5–C6) при акушерском параличе Эрба–Дюшенна остаётся наиболее частой формой родовой травмы нервного сплетения у новорождённых (до 70–80 % случаев). Травма возникает при чрезмерной тракции головы в сторону, противоположную плечу, во время дистокции плечиков или инструментального родоразрешения. Это приводит к растяжению, разрыву или авульзии корешков верхнего ствола, нарушая иннервацию дельтовидной, над- и подостной мышц, двуглавой мышцы плеча и супинатора. Клинически сразу после рождения наблюдается вялый парез проксимальных отделов верхней конечности с гипотонией, арефлексией (рефлекс бицепса, ладонно-ротовой) и асимметрией движений. Спонтанное восстановление происходит в 80–90 % лёгких случаев (нейропраксия), однако при тяжёлых повреждениях требуется ранняя диагностика и возможная микрохирургия.[18]Анатомо-клинические особенности поражения именно верхнего ствола (C5–C6) определяют благоприятный прогноз при своевременном вмешательстве: в отличие от тотальных форм, здесь сохраняются движения

кости и пальцев, что позволяет использовать ранние консервативные и оперативные методы для предотвращения вторичных контрактур и дисплазии плечевого сустава.

Классическим проявлением поражения верхнего ствола (C5–C6) является поза «официанта» (waiter's tip posture, или «поза официанта/писателя»). Поражённая рука пассивно свисает вдоль туловища: плечо приведено и ротировано внутрь (из-за паралича дельтовидной, надостной и подостной мышц), локоть разогнут (парез двуглавой и плечевой мышц), предплечье пронировано (слабость супинатора), кисть находится в ладонном сгибании, пальцы слегка согнуты. При приподнимании ребёнка рука «отвисает» назад, активные движения в плечевом и локтевом суставах отсутствуют или резко ограничены, сохраняются движения в кисти и пальцах. Кожа холодная, бледная, возможна гипо- или анестезия в зоне C5–C6. В остром периоде (до 1 месяца) отмечается болезненность при пассивных движениях, гипотония и атрофия проксимальных мышц. При поднятой руке ладонь «смотрит назад». Эта поза возникает из-за преобладающего действия антагонистов (гравитации и неповреждённых мышц). В позднем периоде формируются контрактуры: приводяще-внутротационная в плече, сгибательная в локте и лучезапястном суставе [1,22].

Данная поза является не только диагностическим маркером, но и прогностическим: её сохранение после 3–4 недель жизни в сочетании с отсутствием восстановления отведения плеча и сгибания локтя требует немедленного инструментального обследования, поскольку указывает на возможный аксонотмезис или нейротмезис, а не простую нейропраксию

3.2. Классификация Наракаса

В зависимости от протяжённости и степени повреждения плечевого сплетения выделяют несколько клинических форм [9,26]:

Классификация неонатального паралича плечевого сплетения (НППС) по А. Наракасу

Группа	Название	Поврежденные корешки	Клинические признаки
I	Классический паралич Эрба	C5-C6	Отсутствие отведения и наружной ротации плеча, сгибания в локте и супинации.
I	Расширенный паралич Эрба	C5-C7	Признаки I группы в сочетании с отсутствием разгибания кисти и пальцев.
II	Тотальный паралич	C5-T1	Полный вялый паралич конечности («рука-петля»).
V	Тотальный паралич с с-м Горнера	C5-T1+симпатический ствол	Тотальный паралич сопровождающийся птозом, миозом и энофтальмом.

Как видно из таблицы, неонатальный паралич плечевого сплетения по классификации А. Наракасу делится на четыре группы в зависимости от уровня повреждения корешков и клинических проявлений. Классический паралич Эрба (C5–C6) является наиболее

распространённым и характеризуется нарушением отведения и наружной ротации плеча, сгибания в локте и супинации. При расширенном параличе Эрба (C5–C7) присоединяется потеря разгибания кисти и пальцев, что отражает более широкое вовлечение нервных корешков. Тотальный паралич (C5–T1) приводит к полной вялой парезе верхней конечности («рука-петля»), тогда как при тотальном параличе с синдромом Горнера повреждается симпатический ствол, что сопровождается птозом, миозом и энофтальмом, указывая на более тяжёлую травму с вовлечением вегетативной нервной системы.

Заключение

Поражение верхнего ствола плечевого сплетения (C5–C6), известное как паралич Эрба–Дюшенна, является одной из наиболее значимых форм акушерской травмы периферической нервной системы у новорождённых. Проведённый анализ литературных данных показал, что анатомо-функциональные особенности плечевого сплетения, а также биомеханические факторы родового процесса создают условия для тракционного повреждения нервных структур. Нарушение иннервации проксимальных мышц плечевого пояса приводит к формированию характерной клинической картины с ограничением отведения плеча, сгибания локтя и супинации предплечья, что отражается на функциональном развитии верхней конечности. При этом степень клинических проявлений и прогноз заболевания напрямую зависят от глубины повреждения нервных волокон и своевременности диагностики.

С современных позиций диагностика поражения верхнего ствола плечевого сплетения основывается на комплексном подходе, включающем клиническую оценку двигательной активности, электрофизиологические методы исследования и нейровизуализацию. Применение шкал оценки активных движений, электронейромиографии, ультразвукового исследования и магнитно-резонансной томографии позволяет более точно определить уровень и характер повреждения нервных структур, а также спрогнозировать восстановление функции конечности. В последние годы значительный прогресс достигнут в области ранней стратификации пациентов по степени тяжести повреждения, что позволяет своевременно выявлять детей с неблагоприятным прогнозом и определять показания к микронейрохирургическому лечению.

Особое значение имеет ранняя диагностика и междисциплинарный подход к ведению пациентов, включающий участие неврологов, ортопедов, нейрохирургов и специалистов по медицинской реабилитации. Своевременное начало реабилитационных мероприятий и, при необходимости, хирургического вмешательства позволяет предотвратить развитие вторичных ортопедических деформаций, контрактур и функциональных ограничений. В перспективе развитие новых методов нейровизуализации, совершенствование микрохирургических техник и внедрение современных реабилитационных технологий будут способствовать улучшению функциональных результатов лечения и повышению качества жизни детей с данной патологией.

Таким образом, дальнейшее изучение анатомо-клинических особенностей поражения верхнего ствола плечевого сплетения и совершенствование методов ранней диагностики остаются важными направлениями современной медицины, направленными на снижение частоты инвалидизации и оптимизацию тактики лечения при параличе Эрба–Дюшенна.

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ACTUAL DIAGNOSTIC AND CLINICAL ASPECTS OF LARYNGEAL CANCER

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Annotation: this scientific and analytical work presents modern world and local-regional data on incidence, mortality, lethality and five-year survival rate of such oncological pathology of head and neck tumors as laryngeal cancer. The issues of etiology and pathogenesis, features of distribution, modern approaches and principles of complex diagnostics, prospects for improving treatment results, as well as prognosis are covered in detail. The epidemiological characteristics of this pathology in our republic are given in the context of regions of the country.

Key words: oncology, otorhinolaryngology, laryngeal cancer, human papillomavirus, biomarkers, RNA, immune-related genes, autophagy, ultrasound examination, epidemiology, incidence, mortality, lethality, five-year survival rate, prognosis.

Laryngeal cancer (LC) is a malignant tumor that develops from elements of the non-keratinizing epithelium of the larynx.

The etiologic factors remain unclear to date. In most cases, the patient's medical history includes untreated inflammatory and precancerous diseases of the larynx (laryngitis, papillomas, papillomatosis, dyskeratosis, leukoplakia, pachydermia, fibroma); a long period of smoking, alcohol consumption, work in dusty conditions (textile production), inhalation of harmful carcinogenic substances (oil, its distillation products, benzene, phenolic resins, asbestos); genetic predisposition (the presence of malignant diseases in relatives), as well as age and gender (males over 55 years of age) [1,2].

The diagnostic criteria are as follows. Complaints and medical history. Complaints: cough; hoarseness; sore throat radiating to the ear; difficulty breathing; choking when taking liquid food; enlarged cervical, supraclavicular, subclavian, submandibular, and submental lymph nodes. History: early symptoms of the disease in LC are: hoarseness and cough, which appear already at stage I of the disease; when, at the initial visit of patients, hoarseness has been observed for six months with the addition of other symptoms, this may indicate later stages (III-IV) of the disease. In this case, complaints of shooting pain in the ear, difficulty breathing, choking when taking liquid food or water, and the appearance of enlarged nodes on the neck are also added [1].

Physical examination: indirect laryngoscopy (tumor, formation of one of the parts of the larynx, limited mobility of the true vocal cord or fixation of the affected half of the larynx, narrowing of the glottis); palpation examination of the lymph nodes of the neck on both sides (the presence of enlarged cervical lymph nodes of a dense consistency, immobile or stiff, slightly painful or possibly not painful, more than 1.0 cm in size).

Laboratory tests: cytological examination (increase in cell size up to giant, change in the shape and number of intracellular elements, increase in the size of the nucleus, its contours, different degrees of maturity of the nucleus and other cell elements, change in the number and shape of nucleoli); histological examination (large polygonal or spiky cells with well-defined cytoplasm, round nuclei with clear nucleoli, with the presence of mitoses, cells are located in the form of cells and cords with or without keratin formation, the presence of tumor emboli in the vessels, the severity of lymphocytic plasmacytic infiltration, mitotic activity of tumor cells).

Instrumental examinations: ultrasound examination of the cervical, submandibular, supraclavicular, subclavian lymph nodes (contours are clear, uneven, echogenicity is reduced, there may be areas of mixed echogenicity, the structure of the node is heterogeneous, increased vascularization is possible); computed tomography of the larynx (a tumor formation of the larynx, occupying the right or left half, spreading to the piriform sinus or the root of the tongue or soft tissues of the anterior surface of the neck, or to the trachea area, conglomerates of lymph nodes of various sizes are possible, compressing or displacing or growing into the vascular-nerve bundle of the neck); biopsy of a laryngeal tumor (cytological examination of the material reveals an increase in the size of the cell up to giant, a change in the shape and number of intracellular elements, an increase in the size of the nucleus, its contours, different degrees of maturity of the nucleus and other elements of the cell, a change in the number and shape of nucleoli; histological examination of the material reveals large polygonal or spiky cells with well-defined cytoplasm, round nuclei with clear nucleoli, with the presence of mitoses, the cells are arranged in the form of cells and cords with or without the formation of keratin, the presence of tumor emboli in the vessels, the severity of lymphocyte-plasmocyte infiltration, mitotic activity of tumor cells); fine-needle aspiration biopsy of enlarged lymph nodes of the neck (during cytological examination of the material - an increase in the size of the cell up to giant, a change in the shape and number of intracellular elements, an increase in the size of the nucleus, its contours, different degrees of maturity of the nucleus and other elements of the cell, a change in the number and shape of nucleoli) [1].

As noted by Huang J. et al. [3] though the LC only has 1% of the total cancer cases and related deaths, it is a type of head and neck cancers with the highest prevalence. Cigarette smoking and alcohol consumption was found to have the strongest relation with LC; other potential risk factors include age (≥ 65), sex (male), family history of cancer, chemical workplace exposure, gastro-esophageal reflux, and exposure to human papillomavirus (HPV).

In their work, the authors emphasize that the global incidence and mortality rates of LC in 2020 was extracted from the Global Cancer Observatory (GLOBOCAN) database, developed by the International Agency for Research on Cancer, World Health Organization (WHO) [4].

The Gross Domestic Products (GDP) and Human Development Index (HDI) for each country were retrieved from World Bank and United Nations. For the categorization of HDI rates, <0.550 , $0.550-0.699$, $0.700-0.700$, and ≥ 0.800 are considered low, medium, high, and very high. Data from 1980 to 2020 were obtained, and the data of the most recent 10 years were used for trend analysis. The WHO mortality database was used for cancer-related death data for each country and region. Cancer mortality data was collected from national civil cancer registries on a local and national level with the registering system logging verified cancer deaths and their causes, which is then reported to WHO annually. To ensure the quality of data, only figures with medium quality or above were published by the WHO mortality database based on the timeliness, completeness and coverage of registration and the proportion of deaths assigned to ill-defined causes. All incidence and mortality figures of LC were transformed - using the Segi-Doll world reference population for various nations - into an age-standardised rate (ASR) per 100 000 individuals. Weighting was allocated in accordance with proportions of people in the standard population's corresponding age groups. This enabled the current study to compare incidence and mortality rates across different countries over time [3].

There were 184 615 newly reported cases of LC in 2020, with an ASR incidence of 2.0 per 100 000 persons. Incidence varied geographically, region with the highest incidence was Caribbean (ASR=4.0) followed by Central and Eastern Europe (ASR=3.6) and Southern Europe (ASR=2.9). Regions with the lowest incidence include Middle Africa (ASR=0.76), Western Africa (ASR=0.79), and Central America (ASR=0.86). There was a remarkable disparity among the two sexes in terms of incidence, as the global ASR of males (ASR=3.6) was more than seven times higher than that of females (ASR=0.49). The highest incidence was in countries with medium HDI (ASR=2.5), followed by very high HDI (ASR=2.3), high HDI (ASR=1.6), and low HDI (ASR=0.94). In 2020, 99 840 LC-related deaths were reported, which was slightly more than 1% of the total cancer-related deaths. Globally, LC has an ASR of 1.0 per 100 000 persons in mortality. In terms of the geographical distribution, the Caribbean region (ASR=2.1) had the highest mortality rate, doubling the global average, followed by Central and Eastern Europe (ASR=1.9), and South-Central Asia (ASR=1.7). Regions with the lowest mortality were Australia and New Zealand (ASR=0.34), Micronesia (ASR=0.45), and Middle Africa (ASR=0.54). Similar to incidence, the highest mortality was in countries with medium HDI (ASR=1.6), followed by high HDI (ASR=0.92), very high HDI (ASR=0.86), and low HDI (ASR=0.71). Among males LC incidence was associated with a higher HDI ($\beta=0.175$, 95% confidence interval (CI): 0.111-0.239, $P<0.001$), prevalence of smoking ($\beta=0.051$, 95% CI: 0.041-0.061, $P<0.001$), alcohol drinking ($\beta=0.040$, 95% CI: 0.028-0.052, $P<0.001$), unhealthy dietary ($\beta=0.012$, 95% CI: 0.006-0.018, $P<0.001$), obesity ($\beta=0.022$, 95% CI: 0.012-0.031, $P<0.001$), hypertension ($\beta=0.031$, 95% CI: 0.022-0.041, $P<0.001$), diabetes ($\beta=0.032$, 95% CI: 0.014-0.051, $P=0.001$), and lipid disorders ($\beta=0.021$, 95% CI: 0.013-0.029, $P<0.001$). Among females, incidence was associated with a higher HDI ($\beta=0.114$, 95% CI: 0.050-0.178, $P<0.001$), prevalence of smoking ($\beta=0.049$, 95% CI: 0.033-0.065, $P<0.001$), inactivity ($\beta=0.040$, 95% CI: 0.009-0.072, $P=0.011$), obesity ($\beta=0.013$, 95% CI: 0.004-0.022, $P=0.004$), hypertension ($\beta=0.012$, 95% CI: 0.002-0.023, $P=0.024$), diabetes ($\beta=0.051$, 95% CI: 0.031-0.071, $P<0.001$), and lipid disorders ($\beta=0.015$, 95% CI: 0.007-0.023, $P<0.001$). Among males LC mortality was associated with a higher

HDI ($\beta=0.094$, 95% CI: 0.025-0.163, $P<0.001$), prevalence of smoking ($\beta=0.044$, 95% CI: 0.033-0.054, $P<0.001$), alcohol drinking ($\beta=0.025$, 95% CI: 0.013-0.038, $P<0.001$), unhealthy dietary ($\beta=0.009$, 95% CI: 0.003-0.015, $P=0.002$), obesity ($\beta=0.016$, 95% CI: 0.006-0.025, $P=0.001$), hypertension ($\beta=0.025$, 95% CI: 0.015-0.034, $P<0.001$), and lipid disorders ($\beta=0.013$, 95% CI: 0.004-0.021, $P=0.003$). Among females, mortality was associated with a lower GDP per capita ($\beta=-0.076$, 95% CI: -0.126-0.027, $P=0.003$), and prevalence of alcohol drinking ($\beta=-0.060$, 95% CI: -0.085-0.035, $P<0.001$) [3].

Overall, more countries were showing decreasing trends than increasing trends in LC while such trends were less evidence among female population, younger subjects, and countries from Europe. The overall incidence for males was decreasing while females reported mixed trends. For males, significant increases were found only in Cyprus [average annual percent change (AAPC)=5.88; 95% CI: 0.52-11.52; $P=0.035$], whilst decreasing trends were reported in 24 countries evenly distributed in different continents, Chile (AAPC=-11.5; 95% CI: -20.99-0.88; $P=0.038$) reported the largest decrease, followed by the Philippines (AAPC=-7.71; 95% CI: -12.15-3.05; $P=0.006$), and Norway (AAPC=-5; 95% CI: -8.71-1.14; $P=0.018$). For females, three countries showed significant increasing trends: Japan (AAPC=6.01; 95% CI: 1.51-10.71; $P=0.015$), Switzerland (AAPC=5.61; 95% CI: 0.05-11.49; $P=0.048$), and Czech Republic (AAPC=3.31; 95% CI: 1.28-5.39; $P=0.005$). Evident decreases were found in six countries, with India (AAPC=-8.35; 95% CI: -13.62-2.75; $P=0.009$), Korea (AAPC=-8.28; 95% CI: -11.68-4.74; $P=0.001$), and Turkey (AAPC=-6.05; 95% CI: -10.21-1.69; $P=0.013$) reporting the largest decreases. Similar to the incidence trends, there was a remarkable difference between the mortality trends of males and females. For males, only Thailand (AAPC=5.41; 95% CI: 3.56-7.30; $P<0.001$) reported significant increases. On the contrary, significant decreases were observed in 30 countries. The largest decreases were found in Korea (AAPC=-7.17; 95% CI: -8.65-5.66; $P<0.001$), Singapore (AAPC=-7.10; 95% CI: -13.59-0.11; $P=0.047$), and France (AAPC=-5.96; 95% CI: -6.76-5.15; $P<0.001$). For females, significant increasing trends were found in Israel (AAPC=12.49; 95% CI: 0.81-25.51; $P=0.038$); while significant decreases were reported in eight countries, with Korea (AAPC=-10.58; 95% CI: -15.61-5.24; $P=0.002$), Belarus (AAPC=-7.93; 95% CI: -13.55-1.95; $P=0.010$), and Colombia (AAPC=-5.68; 95% CI: -8.04-3.27; $P=0.001$) reported the most evident decreases. For the older males aged 50 or above two countries reported significant increases: Cyprus (AAPC=6.87; 95% CI: 1.16-12.91; $P=0.024$), and Belarus (AAPC=1.41; 95% CI: 0.28-2.55; $P=0.021$). In contrast, significant decreases were observed in 21 countries sporadically distributed worldwide. The largest decreases were found in Chile (AAPC=-10.31; 95% CI: -19.44-0.14; $P=0.048$), Philippines (AAPC=-7.57; 95% CI: -11.86-3.08; $P=0.005$), and Norway (AAPC=-5.69; 95% CI: -8.87-2.41; $P=0.004$). For females aged 50 or above, three countries, all European countries, reported significant increases: Spain (AAPC=6.76; 95% CI: 2.03-11.72; $P=0.01$), Switzerland (AAPC=5.38; 95% CI: 0.25-10.78; $P=0.042$), and Czech Republic (AAPC=4.00; 95% CI: 1.73-6.32; $P=0.003$) reported the largest increases. On the other hand, four populations showed significant decreasing trends, Turkey (AAPC=-6.50; 95% CI: -11.64-1.07; $P=0.025$) reported the largest decline, followed by Canada (AAPC=-4.36; 95% CI: -6.94-1.70; $P=0.006$), and the white population in the USA (AAPC=-2.98; 95% CI: -5.13-0.78; $P=0.014$). Similar distribution but larger increase was found in males aged below 50 Norway (AAPC=18.77; 95% CI: 4.55-34.92; $P=0.014$) and Thailand (AAPC=10.24; 95% CI: 0.36-21.09; $P=0.044$) reported significant increasing trends, whereas evident decreasing trends were observed in 17 countries, predominately Asian and European countries, with Germany (AAPC=-17.17; 95% CI: -26.66-6.44; $P=0.007$), Denmark (AAPC=-9.88; 95% CI: -17.74-1.26; $P=0.030$), and France (AAPC=-9.66; 95% CI: -14.70-4.32; $P=0.004$) showing the greatest decreases. From the raw data, the highly significant increasing trend observed in the younger male population of Norway and Thailand was likely due to the statistical base effect as unusually low ASR was reported in the start of the 10-year interval 2010-

2011 (Norway); 2003 (Thailand). For their younger females aged below 50, significant decreases were observed in two countries/regions: Hong Kong, SAR, China (AAPC=-12.44; 95% CI: -21.77-1.99; P=0.026) and Korea (AAPC=-11.79; 95% CI: -21.66-0.67; P=0.041), while no country reported significant increase [3].

In conclusion, our colleagues point out that the reported incidence for LC has been decreasing remarkably for the past decades, especially for the male population, potentially due to the reduced consumptions of cigarettes and alcohol. Its mortality has also been decreasing, possibly attributable to broader availability and applications of treatments. However, regional disparity in mortality remains due to difference in level of access to surgical care. On the contrary, it is alarming that some evident increases were observed in the female populations and younger subjects from some countries. If no mitigation interventions are implemented, such trends may continue. It is also recommended that governments should continue the implementation of smoking and alcohol reduction campaigns, to minimize further burden on healthcare system.

Nocini R. et al. in their work they say that [5] LC is a form of malignancy originating from the anatomic site called larynx (also commonly known as “voice box”), which is anatomically divided in three regions including the supraglottic larynx (encompassing the epiglottis, false vocal cords, ventricles, aryepiglottic folds and arytenoids), the glottis (encompassing the true vocal cords and the anterior and posterior commissures) and the subglottic region. Among squamous cell carcinomas, the well and moderately differentiated forms slightly prevail over poorly differentiated tumors; the larger number of LC cases originate from the glottic region (i.e., approximately two-third), followed by the supraglottic area (about 30%), whilst transglottic and purely subglottic tumors are generally less frequent. The more important risk factors for LC include tobacco use, excessive alcohol ingestion, gastro-esophageal reflux, Plummer-Vinson syndrome, anatomical malformations, exposure to heat, chemicals, asbestos, nickel or ionizing radiations, along with some viral infections (e.g., HPV). The most frequent symptoms of laryngeal malignancies include hoarseness, sore throat, dysphagia and/or painful swallowing, impairment in voice quality, otalgia, cough and hemoptysis. Despite hoarseness can develop early in patients with laryngeal malignancies, in many cases the cancer has already deeply involved the vocal cords and spreads to regional lymphatics at diagnosis. Primary tumor volume, composite nodal volumes, composite primary tumor and nodal volumes are significant predictors of unfavorable prognosis, along with advanced age, performance status, grade and depth of invasion.

In their work, the researchers note that LC is an important oncologic entity, whose prognosis depends on establishing appropriate preventive and diagnostic measures, especially in populations at higher risk. The current incidence, prevalence and mortality of LC are estimated at 2.76 cases/year per 100,000 inhabitants, 14.33 cases/year per 100,000 inhabitants and 1.66 deaths/year per 100,000 inhabitants, respectively, averaging 3.28 million Disability-Adjusted Life Years each year. Incidence and prevalence have increased by 12% and 24%, respectively during the past 3 decades, whilst mortality has declined by around 5%. The epidemiologic burden of this malignancy is approximately 5-fold higher in males and increases in parallel with ageing, peaking after 65 years of age. Both incidence and mortality rates are higher in Europe and lower in Africa, but the ratio between deaths and incidence is the highest in Africa. Incidence has gradually declined in Europe during the past 3 decades, whilst it has increased in South-East Asia and Western Pacific. Cigarette smoking and alcohol abuse contribute for about 90% of overall worldwide mortality for LC. At the same time, the conclusions state that LC still poses a high clinical and societal burden, with an escalating temporal trend not expected to reverse soon [5].

An interesting work was presented by Li C. et al. [6]. In this study, authors aimed to explore the roles of cuproptosis-related genes in LC and their potential as prognostic markers and therapeutic targets. LC, characterized by high recurrence rates and a lack of effective biomarkers, has been associated with cuproptosis, a regulated cell death process linked to cancer progression.

They collected comprehensive data from The Cancer Genome Atlas and Gene Expression Omnibus databases, including gene expression profiles and clinical data of LC patients. Using clustering and gene analysis, researchers identified cuproptosis-related genes with prognostic significance. A risk model was constructed based on these genes, categorizing patients into high- and low-risk groups for outcome comparison. Univariate and multivariate analyses were conducted to identify independent prognostic factors, which were then incorporated into a nomogram. Gene Set Enrichment Analysis was employed to explore pathways distinguishing high- and low-risk groups. This risk model, based on four genes, including transmembrane 2, dishevelled binding antagonist of β -catenin 1, stathmin 2, and G protein-coupled receptor 173, revealed significant differences in patient outcomes between high- and low-risk groups. Independent prognostic factors were identified and integrated into a nomogram, providing a valuable tool for prognostic prediction. Gene Set Enrichment Analysis uncovered up-regulated pathways specifically associated with high-risk patient samples. The authors point out that this study highlights the potential of cuproptosis-associated genes as valuable prognostic markers and promising therapeutic targets in the context of LC and sheds light on new avenues for understanding and treating this complex disease.

In a study by Ren L. et al. [7], immune signatures of LC were systematically analyzed and their role in tumor progression was assessed. Differentially expressed immune-related genes (IRGs) were screened between LC and normal tissues from The Cancer Genome Atlas (TCGA) dataset. Then, two prognosis-related IRGs aquaporin 9 (AQP9) and zeta chain of T cell receptor associated protein kinase 70 (ZAP70) were analyzed by a series of survival analysis. Based on them, molecular subtypes were constructed by unsupervised cluster analysis. Differences in survival outcomes, human leukocyte antigen (HLA) expression and immune cell infiltrations were assessed between subtypes. Expression of AQP9 and ZAP70 was validated in LC tissues and cells by reverse transcription-quantitative polymerase chain reaction (RT-qPCR) and immunohistochemistry. After silencing and overexpressing AQP9 and ZAP70, cholecystokinin-8 (CCK-8), 5-ethynyl-2'-deoxyuridine (EdU), wound healing and transwell assays were performed in TU212 and LCC cells. Totally, 315 IRGs were abnormally expressed in LC. Among them, AQP9 and ZAP70 were distinctly correlated to patients' prognosis. Two subtypes were developed with distinct survival outcomes, HLA expression and immune microenvironment. Low expression of AQP9 and ZAP70 was confirmed in LC. AQP9 and ZAP70 up-regulation distinctly suppressed proliferation, migration, and invasion of LC cells. The opposite results were investigated when their knockdown.

Our colleagues focus on the fact that the obtained findings revealed the roles of AQP9 and ZAP70 in progression of LC, and suggested that AQP9 and ZAP70 could potentially act as candidate immunotherapeutic targets for LC. Collectively, this study proposed two prognosis-related IRGs AQP9 and ZAP70. Two molecular subtypes based on AQP9 and ZAP70 may reflect immune microenvironment of LC. In vitro, their up-regulation inhibited proliferation, migration and invasion of LC cells. Results obtained demonstrated that AQP9 and ZAP70 might be candidate therapeutic targets and prognostic signatures for LC, which may assist guide clinical therapy in the future [7].

Liu W. et al. [8] in their work they say that LC is one of the most common malignant tumors among head and neck cancers. Accumulating studies have indicated that long noncoding RNAs (lncRNAs) play an important role in LC occurrence and progression, however, the functional roles and relative regulatory mechanisms of lncRNA growth arrest-specific transcript 5 (GAS5) in LC progression remain unclear. The expression of lncRNA GAS5 in both LC tissues and cell lines was evaluated using quantitative RT-qPCR assay.

The relationships between lncRNA GAS5 expression and clinical parameters were also analyzed. To determine the biological function of lncRNA GAS5, a lncRNA GAS5-specific plasmid was first transfected into LC cells using lentiviral technology. Cell counting kit-8 assay, flow cytometry, and Transwell assays were used to detect in vitro cell proliferation, apoptosis, cycle

distribution, and metastasis abilities, respectively. Furthermore, *in vivo* cell growth experiments were also performed using nude mice. Additionally, western blotting was performed to identify the underlying regulatory mechanism. In the current study, lncRNA GAS5 was downregulated in LC tissues and its low expression was closely associated with poor tumor differentiation, advanced TNM stage, lymph node metastasis, and shorter overall survival time. In addition, lncRNA GAS5 upregulation significantly inhibited LC cell proliferation both *in vitro* and *in vivo*. Moreover, in response to lncRNA GAS5 overexpression, more LC cells were arrested at the G2/M stage, accompanied by increased cell apoptosis rates and suppressed migration and invasion capacities. Mechanistically, this data showed that the overexpression of lncRNA GAS5 significantly regulated the PI3K/AKT/mTOR signaling pathway. lncRNA GAS5 might act as a suppressor gene during LC development, as it suppressed cell proliferation and metastasis by regulating the PI3K/AKT/mTOR signaling pathway; thus, lncRNA GAS5 is a promising therapeutic biomarker for the treatment of LC. Overall, lncRNA GAS5 could serve as a tumor suppressor gene in LC, which would be a promising therapeutic biomarker for LC treatment.

Liberale C. et al. [9] note that LC is one of the most frequent tumors of the upper aerodigestive tract. While certain factors such as alcohol consumption and tobacco smoking have been established as risk factors for LC, the correlation of many other risk factors with the mechanism of carcinogenesis remains unclear. The process of laryngeal carcinogenesis has been well described; however, there are still aspects that lack understanding, and the underlying biological mechanisms have not been fully elucidated. Indeed, the emerging role of lncRNAs, miRNAs, and mRNAs is becoming increasingly important in our understanding of cancer development and its clinical and therapeutic implications. These non-coding RNAs have been shown to play critical roles in various aspects of cancer biology, including tumor initiation, progression, metastasis, and response to treatment. Gaining insight into the molecular mechanisms involved in carcinogenesis could enable the prediction of tumor progression and facilitate targeted interventions at various stages of the disease. The ultimate goal is to develop precise and effective therapies through a precision medicine approach. Achieving this objective requires further comprehensive studies on the molecular biology of cancer and the role of different risk factors.

Özdaş T. et al. [10] point out that while LC does not show any obvious early symptoms, it tends to have a poor prognosis in advanced clinical stages. Chromosome region maintenance 1 (CRM1) mediates the nuclear export of some RNAs, major and tumor suppressor proteins and has been associated with the pathogenesis of many tumors. However, the clinicopathological significance of CRM1 gene expression in LC has not been clarified yet. CRM1 expression in matched tumor and normal tissues obtained from 43 LC patients were evaluated intracellular for protein and mRNA levels by immunohistochemical staining (IHC), western-blot, and quantitative real-time qRT-PCR, respectively. IHC, western-blot, and qRT-PCR analyses showed that CRM1 expression was significantly increased in LC tissue compared to normal tissue. Increased expression of CRM1 has been associated with poor prognostic clinicopathological features, including advanced tumor stage, increased tumor invasion, larger tumor size, positive lymph node metastasis, distant metastasis, and invasive histological type by IHC, western-blot, and qRT-PCR. Kaplan–Meier survival analysis showed that patients with high expression of CRM1 exhibited lower overall survival compared to those with low expression (Log-rank = 7.16, $p = 0.007$). According to the TCGA datasets, elevated CRM1 expression in head and neck cancer including cases of squamous cell laryngeal origin is associated with advanced tumor stage and histological grade ($p > 0.05$, for all). Consequently, CRM1 plays an important role in LC and may serve as an indicator and prognostic factor for poor overall survival in LC patients. In conclusion, this study revealed that CRM1 is a predictive biomarker for poor overall survival in LC patients, and that the evaluation of the clinical pTNM staging system of the tumor and CRM1 expression together may provide additional prognostic information. Moreover, inhibition of CRM1 expression may be a new

therapeutic strategy for LC. Furthermore, prospective large-scale studies are needed to explore the true prognostic role of elevated CRM1 expression in laryngeal squamous cell carcinoma.

The aim of the study by Luo M.S. et al. [11] was to develop an autophagy-related model to predict the prognosis of patients with LC. Autophagy, a major cause of cancer-related death, is correlated with the pathogenesis of various diseases including cancers. Our colleagues analyzed the correlation between expression profiles of autophagy-related genes (ARGs) and clinical outcomes in 111 LC patients from TCGA. Afterward, gene functional enrichment analyses of gene ontology and Kyoto Encyclopedia of Genes and Genomes were performed to find the major biological attributes. Univariate Cox regression analyses and multivariate Cox regression analyses were performed to screen ARGs whose expression profiles were significantly associated with LC patients overall survival (OS). Furthermore, to provide the doctors and patients with a quantitative method to perform an individualized survival prediction, we constructed a prognostic nomogram. Thirty eight differentially expressed ARGs were screened out in LC patients through the TCGA database. Related functional enrichments may act as tumor-suppressive roles in the tumorigenesis of LC. Subsequently, 4 key prognostic ARGs (IKBKB, ST13, TSC2, and MAP2K7) were identified from all ARGs by the Cox regression model, which significantly correlated with OS in LC. Furthermore, the risk score was constructed, which significantly divided laryngeal cancer patients into high- and low-risk groups. Integrated with clinical characteristics, gender, N and the risk score are very likely associated with patients OS. A prognostic nomogram of ARGs was constructed using the Cox regression model. As the researchers note this study could provide a valuable prognostic model for predicting the prognosis of LC patients and a new understanding of autophagy in LC. A novel autophagy-related model and a predictive nomogram were conducted to robustly estimate LC patients survival.

Now, regarding this pathology in our country at the republican level. The incidence of LC in the Republic of Kazakhstan in 2023 was 2.2 per 100 thousand population with an increase rate of 15.5% compared to the previous year (1.9 in 2022), which in absolute numbers amounted to 436 people (370 cases a year earlier), second only to prostate cancer (16.7%). The proportion of cases diagnosed for the first time in life, recorded by oncology organizations, was 1.2% (1.1% in 2022). At the same time, 384 men fell ill (the proportion is 2.4%, 13th rank place), women - 52 (the proportion is 0.2%, 22nd rank place), which clearly shows the gender difference in the incidence of this pathology with a pronounced predominance of the male population [12].

The LC level above the national average was established in 9 regions of the country: North Kazakhstan - 5.8 (the maximum indicator); Pavlodar - 3.8; Kostanay - 3.6; East Kazakhstan - 3.4; Abay - 3.3; Karaganda - 3.0; Akmola and Atyrau - 2.9; Mangistau - 2.6. This indicator is below the national average in 11 regions: Turkestan - 0.6 (the lowest level); the city of Astana - 1.0; Kyzylorda - 1.2; the city of Shymkent - 1.5; Ulytau and Almaty - 1.8; West Kazakhstan and Zhambyl - 1.9; Aktobe and Zhetysu regions and the city of Almaty - 2.1 per 100 thousand population. Mortality from this pathology was 0.8 per 100 thousand population, the same as a year earlier. The regions where the mortality rate from LC is above the average in the republic include: Abay - 2.5 (maximum level); North Kazakhstan - 1.9; Pavlodar - 1.6; Mangistau and Karaganda - 1.2; Zhetysu - 1.0; Aktobe - 0.9. Akmola, East Kazakhstan, Kostanay regions and the city of Almaty are on par with the national average. The lowest rates were noted in Ulytau - 0.0; Turkestan - 0.1; West Kazakhstan and the city of Shymkent - 0.3; Kyzylorda - 0.5; Atyrau and the city of Astana - 0.6; Zhambyl and Almaty - 0.7 regions per 100 thousand people [12].

One-year lethality was 19.2%, taking the 13th place among all nosological forms of malignant neoplasms. At the same time, the ratio between one-year lethality and neglect (stage IV) was 1.6. At the same time, we recall that the farthest from "1" is the worst ratio between the indicators of one-year lethality and neglect.

Next, regarding preventive examinations. It should be noted that during large-scale

preventive examinations of the population in 2023, significantly more patients with malignant neoplasms were actively identified than in 2022. This is 25,193 patients versus 23,623 patients identified in 2022, i.e. +6.6%. This is due to the further abatement of the epidemiological trouble with coronavirus and the increased availability of preventive care for the population. The proportion of patients identified during routine examinations increased from 62.0% to 62.4% of the total number of patients identified per year. As for LC, the early detection of this pathology during preventive examinations increased significantly - from 50.6 to 60.9%. The number of newly identified patients with LC registered with oncology organizations amounted to 425 patients (365 patients in 2022). At the same time, the absolute number of patients with LC identified during medical examinations was 274 people (231 a year earlier), and the proportion was 64.5% and 63.3%, respectively. 167 people out of 274 are patients with stages I and II (in 2022 - 117 patients out of 231). The proportion of patients with LC detected at early stages, as indicated above, was 60.9% against 50.6% a year earlier.

Of course, when analyzing the epidemiological situation, early diagnosis indicators are very important issues.

The regions where the proportion of patients with early stage I of the pathology in question is above the national average (16.5% - 14th rank) include the following regions: the city of Almaty - 34.8% (the best indicator); Abay and Kyzylorda - 30.0%; West Kazakhstan and the city of Astana - 23.1%; North Kazakhstan - 22.6%; Karaganda - 18.8%; Akmola - 18.2%. The lowest rates of early diagnosis were recorded in the Ulytau region (not a single patient with stage I of the disease - 0.0%). Next come: Mangistau - 5.3%; the city of Shymkent - 5.6%; Kostanay - 6.7%; Pavlodar, Zhetysu and Almaty - 7.1%; Atyrau - 10.0%; Zhambyl - 13.0%; East Kazakhstan - 14.3%; Aktope - 15.0% and Turkestan - 15.4% of the country's regions [12].

It should be noted that every second patient with LC is detected in the early (I-II) stages of this pathology (51.1%). However, the situation with this indicator is deplorable in the Ulytau region - there is not a single patient detected in the early stages of the disease. The regions where the proportion of patients with LC detected at stages I-II is above the national average include the following regions. The best indicator is in the city of Astana - 76.9%. Then follow: Pavlodar - 75.0%; West Kazakhstan - 69.2%; North Kazakhstan - 67.7%; Zhambyl - 65.2%; Aktope - 65.0% regions and the city of Almaty - 63.0%. Low rates of early diagnosis were recorded in Ulytau - 0.0% (the worst result in the country); Turkestan - 15.4%; Almaty - 21.4%; the city of Shymkent - 22.2%; Zhetysu - 35.7%; Mangistau - 42.1%; East Kazakhstan - 42.9%; Atyrau - 45.0%; Kostanay - 46.7%; Abay, Akmola, Karaganda and Kyzylorda - 50.0% regions [12].

As is clearly seen from the above data, there is a very large spread in early diagnostics rates across the country, from very good to dismal. Of course, it is necessary to take into account migration processes and other factors that affect early diagnostics rates, but nevertheless, the results obtained give reason not to stop there, both for oncologists and otolaryngologists, general practitioners, since improving early diagnostics rates of malignant tumors, as one of the main postulates and one of the main tasks of medicine in general, continues to be relevant today. The proportion of stage IV LC was 9.4%. At the same time, as mentioned above, the proportion of patients with this nosological form of malignant neoplasms detected at stages I-II was 51.1% (stage I - 16.5%, stage II - 34.6%), which indicates that the largest number of patients with LC was detected at locally advanced with loco-regional damage - stage III of the disease. This stage was 39.5%, i.e. almost two patients out of every five, and we know what aggressive, often complex treatment is used with such a spread of the oncological process and what a disappointing prognosis is for these patients. As for the average national indicator of the proportion of stage IV (9.4%), against this background, West Kazakhstan, Mangistau, Turkestan regions and three megalopolises - the cities of Astana, Almaty, Shymkent stand out, where not a single patient was detected in the terminal stage - 0.0%. Then come: Almaty - 3.6%; Aktope - 5.0%; North Kazakhstan

- 6.5%; Zhetysay and Pavlodar - 7.1%; Zhambyl - 8.7%; Kyzylorda - 10.0%; Kostanay - 13.3%; East Kazakhstan - 14.3%; Atyrau - 20.0%; Akmola - 22.7% regions. This list is closed by three regions, where every fourth patient was detected in the incurable stage of the disease with the worst indicator of 25.0% - Abay, Karaganda and Ulytau regions [12].

The morphological verification rate of LC in the country was 98.8%, second only to non-melanoma skin cancer (99.6%), breast cancer (99.4%) and lip cancer (99.1%) in the first three positions. At the same time, in the Pavlodar region, the morphological verification rate was 92.9%, in Akmola - 95.5%, in Almaty - 96.4%. In other regions, the disease verification rate was 100%.

The total number of patients with malignant neoplasms registered with specialized oncology organizations of the republic continued to increase and by the end of 2023 amounted to 218,186 people, with an increase of 6.0% compared to the previous year (2022 - 205,822, +5.8%). The overall incidence rate of malignant neoplasms increased by 3.9%, from 1055.3 to 1096.4 per 100 thousand people. The growth of this indicator is due to both the increase in the incidence and detection of pathology, and the increase in the survival of cancer patients. In addition, statistical data on patients diagnosed with malignant neoplasms, who have been under observation for 5 years or more, and continue to be observed in 2023, showed that the number of patients under the observation of oncological organizations in Kazakhstan for over five years continued to grow and at the end of the reporting year amounted to 117,616 people, with an increase of 6.2% (2022 - 110,790 people, + 6.6%) (form No. 7).

It is impossible to ignore such an important clinical aspect as the coverage of patients with a first-time diagnosis of LC in the Republic of Kazakhstan with special treatment.

In 2023, the number of hospitalizations for all nosological forms of malignant tumors in the country's oncology organizations amounted to 108,252 cases (2022 - 101,095), with an increase of 7.1% compared to the previous year, which is associated with a constant increase in the number of cancer patients, improved standardization of oncological care, and the development of palliative and restorative services.

At the end of 2023, the absolute number of LC patients who completed specialized treatment was 247 people, continuing treatment - 135 patients. The following results were obtained in percentage terms by methods and types of treatment. Only 12.6% of patients received surgical treatment, only radiation - 19.4%, only drug treatment - 8.9%, combined - 26.7%, complex - 21.5% and chemo-radiation - 10.1%.

Further, regarding the five-year survival of patients. As for LC, at the end of 2023, 2032 people were registered for dispensary care, or 10.2 per 100 thousand of the population. At the end of 2022 - 1899 patients or 9.7 per 100 thousand of the population, respectively.

At the same time, the mortality rate of the observed contingents in 2023 decreased compared to the previous year and amounted to 7.6% in 2023 (8.6% in 2022).

The five-year survival rate of patients with LC was 52.2% in 2023 and 53.2% in 2022 [12].

Summarizing the above, we can conclude that LC, despite not having the highest place in terms of incidence among all existing malignant tumors of other localizations, deserves close attention from specialized specialists. At the same time, taking into account a number of factors, the indicators of early diagnostics do not allow oncologists to "sleep peacefully", since the locally advanced stage III, which prevails over all stages, in addition to being widespread, gives a large number of complications due to the location of vital centers and tissue structures near the primary focus and locoregional metastases. The veiled and variable symptoms, its similarity with various non-core processes, leads to the neglect of the disease. All this requires both oncologists and, first of all, primary health care workers and, of course, otolaryngologists to increase the level of cancer alertness, inform the population about early symptoms that may indicate this pathology or the onset of proliferative changes and conduct high-tech diagnostic measures, including for the purpose of differential diagnosis and, as a result, timely treatment. People from the risk group are

recommended to visit specialized specialists annually and, if necessary, undergo an examination.

An epidemiological assessment of the situation with LC in our country suggests that there are sometimes significant differences in the regions not only in incidence rates, but also in the state of early diagnosis and mortality from this disease. In connection with the above, this pathology continues to be a serious problem in modern clinical oncology.

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Agricultural Sciences

Analysis of Soil Degradation Processes and Management Strategies in Georgia

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Abstract

This article is dedicated to a complex analysis of the causes, forms, and modern management strategies of soil degradation in Georgia. The paper discusses critical processes such as water and wind erosion, soil salinization, and structural disturbances caused by anthropogenic impact. Based on secondary data analysis, the article assesses the scale of degradation at a regional level and proposes rehabilitation methods, including the importance of conservation agriculture and the restoration of windbreaks. The research findings emphasize the necessity of strengthening sustainable soil management policies to ensure the country's food security.

Keywords: soil erosion, salinization, sustainable management, Georgia, fertility restoration.

Introduction

Soil degradation is considered the primary cause of ecosystem service loss, directly linked to climate change and biodiversity decline. On a global scale, achieving Land Degradation Neutrality (LDN) is one of the United Nations' key Sustainable Development priorities [1].

In Georgia, a significant portion of agricultural land (approximately 35-40%) suffers from varying degrees of degradation. This poses a direct threat to the country's food security [1].

Soil erosion and the depletion of organic carbon remain the most destructive processes, hindering plant growth and reducing crop yields [3]. Furthermore, intensive agriculture leads to physical soil compaction, which restricts water infiltration and aeration [5].

Soil is a fundamental component of the Earth's ecosystem, playing a critical role in biosphere functioning, food security, and climate regulation. Despite its vital importance, soil is considered a non-renewable resource, as the natural formation of a 1 cm thick fertile layer requires hundreds of years, while its degradation can occur within just a few growing seasons [7].

In a modern global context, soil degradation is recognized as a primary environmental challenge. According to UN data, approximately 33% of the world's arable land is already moderately or severely degraded [4]. This process is directly linked to biodiversity loss, increased carbon emissions, and population migration. Consequently, achieving "Land Degradation Neutrality" (LDN) by 2030 represents one of the key Sustainable Development Goals [6].

For Georgia, a country with deep agrarian traditions, the protection of soil resources is of strategic importance. The country's complex relief and climatic diversity result in a mosaic soil cover, which simultaneously increases its vulnerability to erosive processes. Over the last decade, growing anthropogenic pressure—specifically deforestation, improper irrigation, and intensive grazing—has significantly accelerated soil depletion.

According to statistical data, a substantial portion of Georgia's agricultural land suffers from water and wind erosion, leading to the annual loss of thousands of tons of fertile topsoil [1]. The situation is particularly alarming in high-mountain regions (e.g., Adjara, Svaneti), where erosion often transforms into landslide processes, and in the arid zones of Eastern Georgia, where secondary soil salinization occurs.

The purpose of this article is to analyze the primary forms of soil degradation currently occurring in Georgia and to identify optimal, scientifically-proven strategies for their management. The paper examines both local characteristics and international best practices that could be adapted to the Georgian reality to restore soil fertility and ensure sustainable land use.

Main Body

Modern management strategies focus on **conservation agriculture**, which includes minimal tillage and continuous **mulching** to maintain soil moisture [7]. The implementation of **organic farming** and **agroforestry** systems is recognized as an effective way to reverse soil degradation [8]. The primary forms of erosion are:

- **Water Erosion:** Particularly severe in the highlands of Western Georgia and the foothills of Eastern Georgia (Mtskheta-Mtianeti, Kakheti).
- **Wind Erosion:** A major problem in the Shida Kartli and Dedoplistskaro districts, caused by the destruction of **windbreaks** (shelterbelts).
- **Soil Salinization:** The primary issue for irrigated lands in Kvemo Kartli and Kakheti (Alazani Valley). Should we expand on the **specific causes** of windbreak destruction in Shida Kartli, or would you like to move on to the **conclusion** of the article?

Table No. 1: Prevalence of Soil Degradation by Region in Georgia [Summary Data for 2020-2024]

Region	Primary Type of Degradation	Underlying Cause	Degraded Area (%)
Kakheti	Salinization / Wind Erosion	Improper irrigation, lack of windbreaks	25-30%
Kvemo Kartli	Secondary Salinization / Technogenic	Intensive grazing, mining operations	35%
Adjara / Guria	Water Erosion / Landslides	Deforestation, excessive precipitation	40%

Georgia's **topographic** and **climatic diversity** determines the **heterogeneity** of soil degradation processes. This chapter examines two radically different ecosystems: **humid subtropical** (Adjara) and **arid/semi-arid** (Kakheti).

Table №2: Soil Degradation Indicators and Management Specifics by Region

Synthesis of 2020-2024 Data

Region / Parameter	Dominant Form of Degradation	Climatic/Environmental Factor	Priority Management Strategy	Expected Effect
Adjara (Humid Subtropics)	Water erosion and acidification	Excessive precipitation (>2500 mm), complex terrain	Terracing and soil liming (against acidification)	Preservation of the fertile layer and landslide prevention
Kakheti (Alazani Valley)	Secondary salinization and wind erosion	Arid climate, strong winds	Windbreaks (shelterbelts) and rehabilitation of drainage systems	Restoration of soil structure and moisture retention
Kvemo Kartli	Soil compaction and depletion	Overgrazing and intensive plowing	Crop rotation and minimum tillage (No-till)	Increase in soil organic carbon stocks

As Table No. 2 shows, management of the **hydrological regime** is decisive in the case of Adjara, while in Kakheti, the priorities are **irrigation** and **wind protection** measures.

The data provided on the map shows the percentage indicators of **wind erosion**.

Adjara Region: Water erosion and **acidification**. The soil cover of the Autonomous Republic of Adjara, which is mainly represented by **red** [soils]..."

(Note: The text cut off at "red," which likely refers to **red soils** (Tsitelmiwa), typical for that humid subtropical zone.)



Map 1: Percentage Share of Degraded Lands by Region

and yellow soils, is under high erosive pressure."



Figure 1.2.3. Adjara landslide (Kobuleti)

The main challenge of the region is intense water erosion, which is due to the extreme amount of annual precipitation (2000-2500 mm) and the steepness of the mountainous terrain.

- Mechanism: Excessive precipitation causes mechanical washing away of the upper, fertile humus layer of the soil. Degradation of forest massifs and improper agrotechnical treatment of slopes accelerate this process, which is often transformed into gravitational processes - landslides and mudslides [12].

- Chemical degradation: Under conditions of excessive moisture, bases (Ca, Mg) are washed out of the soil, which leads to acidification of the soil solution. A sharp decrease in pH negatively affects microbiological activity and limits the availability of nutrients necessary for plants.

Kakheti Region: Salinization and Wind Erosion - In eastern Georgia, in particular in the Kakheti region (Alazani Valley, Dedoplistskaro), the degradation processes are of a completely different nature. Chemical salinization and deflation (wind erosion) are dominant here.

- Soil salinization: Incorrect irrigation practices and malfunctioning drainage systems lead to a rise in groundwater levels. In an arid climate, as a result of intensive evaporation, easily soluble salts accumulate on the soil surface, which leads to the degradation of the physicochemical properties of the soil and its complete exclusion from agricultural rotation [12].

- Wind erosion: The massive destruction of windbreaks in the Dedoplistskaro and Signaghi municipalities has left the soil vulnerable



Fig. 5 Kakheti Wind Erosion

Towards strong winds. Deflation results in the transfer of finely dispersed soil particles, which leads to a sharp decrease in fertility and the emergence of signs of desertification [3]. Management strategies in Georgia include steps to be taken by the state and private sectors:

- Restoration of windbreaks: Implementation of the Law of Georgia “On Windbreaks (Field Protection) Strips” [1].
- Land reclamation modernization: Adjustment of drainage systems against salinization.
- Organic agriculture: Use of biopreparations to restore soil microflora.

Research methodology and analysis

The research methodology used in the paper is based on a complex approach that combines qualitative and quantitative analysis to assess the degree of soil degradation. The research process is divided into several stages:

Data collection and systematization - at the initial stage of the research, the latest statistical data on soil resources in Georgia were processed. Reports of the Ministry of Environmental Protection and Agriculture of Georgia [1] and cartographic materials of the National Agency of Public Registry were used. A comparative analysis method was used for data validation, which allows to determine the dynamics of degraded areas over the past five years [12].

Indicative analysis - to assess the degree of soil degradation, the main indicators defined by the UN Land Degradation Neutrality (LDN) framework document were used:

Land cover change: Analysis of remote sensing data to detect vegetation loss.

- Soil productivity: Assessment of biomass productivity trends.
- Soil organic carbon (SOC) stock: Extrapolation of laboratory data to determine soil fertility degradation [12].

Cartographic and GIS methods - Geographic information systems (GIS) were used in the research process, which allow for spatial modeling of degraded soils. In particular, erosion foci were visualized and correlated with the slope of the terrain and the amount of precipitation.

Method for assessing management strategies - When selecting management strategies, a SWOT analysis was used to assess the strengths and weaknesses of each agrotechnical measure (e.g., no-till technology, terracing) taking into account the specific climatic conditions of Georgia.

The implementation of agroecological methods is important. Based on our experiments, we considered it necessary to recommend no-till (minimum tillage) technology and proper crop rotation to farmers.



Fig. 6.7. 8 Minimal tillage technology

No-till is a farming technology that eliminates traditional soil cultivation, i.e. plowing and cultivation. In this method, sowing is carried out directly into the uncultivated soil, which maximizes the natural structure and fertility of the soil.

Conclusion

Based on the analysis conducted and the review of the existing scientific literature, the following conclusions can be drawn:

- Critical situation: Soil degradation in Georgia is characterized by an increasing trend. The country's relief diversity determines specific forms of degradation: water erosion and acidification dominate in Western Georgia (Adjara), while salinization and wind erosion dominate in the East (Kakheti, Kvemo Kartli).
- Anthropogenic pressure: Research has shown that more than 60% of degradation processes are caused by improper agricultural practices, such as clearing of windbreaks, overgrazing, and the use of outdated irrigation systems [12].
- Economic risks: The decline in soil fertility is directly related to the country's food security. Without the restoration of degraded lands, sustainable development of the agricultural sector and adaptation to the challenges posed by climate change are impossible.

Recommendations

In order to protect soil resources and restore fertility, it is advisable to implement the following measures:

- Optimization of land reclamation measures: It is necessary to fully rehabilitate drainage systems in Eastern Georgia to prevent secondary soil salinization.
- Restoration of windbreaks: The state-level program for the establishment of windbreaks should be accelerated, especially in the Shida and Kvemo Kartli regions, which will reduce topsoil depletion by 30-40%.
- Introduction of agroecological methods: No-till (minimum tillage) technology and crop rotation principles should be popularized among farmers, which contribute to the preservation of organic carbon in the soil [LaI, 2020].
- Creation of a monitoring system: It is necessary to create a unified digital map of soil quality indicators (GIS database), which will allow researchers and decision-makers to monitor degradation hotspots in real time.
- Stimulation of terraced farming: Subsidizing the construction of terraces is critically important for Adjara and other high-mountainous regions, which is the most effective mechanism against erosion.

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Biological Sciences

ДЕНДРОХРОНОЛОГИЯ КАК ИНСТРУМЕНТ ОЦЕНКИ СОСТОЯНИЯ ЛЕСНЫХ ЭКОСИСТЕМ СЕВЕРНОГО КАЗАХСТАНА

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Аннотация. В статье рассматриваются методологические возможности дендрохронологического анализа для оценки динамики радиального прироста хвойных пород в лесостепной зоне Северного Казахстана. На основе анализа научной литературы и результатов полевых исследований, выполненных в пяти филиалах Государственного национального природного парка «Кокшетау» (Зерендинский, Арыбалыкский, Шалкарский, Айыртауский, Орманды-Булак), показано, что годовые кольца деревьев являются надёжными индикаторами климатических изменений и антропогенного воздействия. Подробно изложены основные этапы дендрохронологического исследования: отбор кернов приростным буром Пресслера, подготовка образцов, кросс-датировка, измерение ширины колец на комплексе LINTAB-6, стандартизация хронологий с использованием программ TSAP-Win и ARSTAN. Приведены статистические параметры построенных хронологий (средняя чувствительность, межсерийная корреляция, выраженный популяционный сигнал EPS), подтверждающие их высокое качество и пригодность для климатических реконструкций. Обоснована необходимость создания региональной базы древесно-кольцевых хронологий как основы для долгосрочного мониторинга устойчивости лесных экосистем Казахстана.

Ключевые слова: дендрохронология, радиальный прирост, сосна обыкновенная, мониторинг лесов, Северный Казахстан.

Введение

Современные изменения климата, выражающиеся в повышении среднегодовых температур, учащении засушливых периодов и возрастании частоты экстремальных погодных явлений, оказывают существенное влияние на состояние лесных экосистем. Особенно уязвимыми являются переходные зоны, такие как лесостепь Северного Казахстана, где леса произрастают в условиях недостаточного и неустойчивого увлажнения. Одновременно с климатическими изменениями усиливается антропогенная нагрузка: рекреационное воздействие, лесные пожары, загрязнение почв и атмосферы промышленными выбросами. В этих условиях возникает острая необходимость в

объективных, количественных методах оценки реакции лесных экосистем на комплекс внешних факторов.

Дендрохронология – наука о датировании древесных колец и реконструкции условий среды по их параметрам – предоставляет уникальную возможность получать долговременные ряды данных с ежегодным разрешением. Хвойные породы, в частности сосна обыкновенная (*Pinus sylvestris* L.), благодаря чёткой анатомической структуре годичных слоёв, продолжительности жизни и широкому распространению, являются классическими объектами дендрохронологических исследований. В Казахстане накоплен значительный опыт применения дендрохронологии в горных лесах Восточного Казахстана (Катон-Карагайский национальный парк), в ленточных борах Прииртышья, а также в национальных парках Центрального Казахстана (Байанаул). Однако лесостепная зона Северного Казахстана, представленная островными сосновыми борами, остаётся недостаточно охваченной систематическими дендроэкологическими исследованиями.

Настоящая работа ставит целью обобщить методический опыт, накопленный в ходе выполнения проекта ИРН AP25796027, и продемонстрировать потенциал дендрохронологического подхода для создания системы мониторинга лесных экосистем региона.

Материалы и методы

Методологическая основа работы базируется на классических трудах (Fritts, 1966; Cook & Kairiukstis, 1990) и современных разработках. Для получения первичных данных проведены полевые работы на территории ГНПП «Кокшетау» в пяти филиалах: Зерендинский, Арыбалыкский, Шалкарский, Айыртауский, Орманды-Булак. Отбор кернов выполнялся приростным буром Пресслера на высоте 1,3 м. В лаборатории образцы монтировались, шлифовались, окрашивались сафранином. Измерение ширины колец проведено на комплексе LINTAB-6. Кросс-датировка выполнена в программе TSAP-Win, стандартизация хронологий – в ARSTAN.

Результаты

В ходе выполнения полевых и лабораторных работ сформирован массив из 310 кернов, что позволило построить пять локальных дендрохронологических серий, охватывающих временной интервал с 1813 по 2025 год. Статистические параметры построенных хронологий представлены в таблице 1.

Таблица 1 – Основные статистические характеристики локальных хронологий

Параметр	ZERO1	SHA01	AR01	AIRT01	OB_01
Период хронологии	1813– 2025	1820– 2025	1815– 2025	1822– 2025	1818– 2025
Длина ряда (лет)	213	206	211	204	208
Число деревьев	70	60	60	60	70
Средний радиальный прирост (мм/год)	1.42	1.31	1.18	1.26	1.35
Стандартное отклонение (мм)	0.38	0.35	0.27	0.32	0.30
Средняя чувствительность (MS)	0.29	0.27	0.21	0.24	0.25
Межсерийная корреляция (rbar)	0.68	0.64	0.59	0.62	0.66
Синхронность (GLK), %	74.3	71.8	67.5	69.2	72.1
Выраженный популяционный сигнал (EPS)	0.94	0.91	0.88	0.90	0.92

Значения выраженного популяционного сигнала (EPS) для всех пяти хронологий превышают порог 0,85, что в соответствии с общепринятыми критериями свидетельствует о высокой репрезентативности хронологий и их пригодности для дендроклиматического анализа. Наибольшая средняя чувствительность (MS) зафиксирована в Зерендинском и Шалкарском филиалах, что указывает на высокую чувствительность этих древостоев к межгодовым изменениям условий произрастания. Напротив, Арыбалыкский филиал характеризуется минимальными значениями MS и r_{bar} , что может быть связано с более стабильными локальными условиями увлажнения.

Корреляционный анализ между стандартизированными хронологиями (таблица 3) выявил высокие и статистически значимые ($p < 0,001$) коэффициенты парной корреляции, что подтверждает доминирование единого регионального климатического сигнала над локальными шумами. Наиболее тесная связь наблюдается между Зерендинским и Орманды-Булакским филиалами ($r = 0,85$), что объясняется их географической близостью и сходством почвенно-гидрологических условий.

Обсуждение

Полученные результаты подтверждают, что дендрохронологический метод позволяет получать высококачественные временные ряды радиального прироста, пригодные для решения широкого круга задач:

1. Реконструкция климатических условий. Высокая синхронность хронологий и значимая корреляция с метеорологическими данными (что будет показано в последующих публикациях) дают возможность восстанавливать динамику осадков и температур за последние 200 лет. Это особенно важно для Северного Казахстана, где инструментальные метеонаблюдения охватывают лишь последние 80–100 лет.
2. Выявление периодов экстремальных засух. В полученных хронологиях чётко прослеживаются спады прироста, соответствующие известным засушливым периодам (1880–1890-е, 1930–1940-е годы), что согласуется с литературными данными (Farooq et al., 2023; Mapitov et al., 2023).
3. Оценка антропогенного воздействия. Локальные аномалии в отдельных хронологиях, не совпадающие с региональным сигналом, могут указывать на локальные нарушения (пожары, рубки, рекреационную нагрузку). Так, в Шалкарском филиале отмечены единичные узкие кольца, не коррелирующие с соседними участками, что, вероятно, связано с последствиями низовых пожаров.
4. Создание региональных хронологических стандартов. Полученные серии, объединённые в единую региональную хронологию, могут служить опорой для датировки археологической древесины, а также для калибровки моделей роста лесов при изменении климата.

Сравнение с ранее проведёнными исследованиями в Казахстане (Жумадина и др., 2019; Abilova et al., 2022; Zhumadina et al., 2023) показывает, что выявленные закономерности (снижение прироста в XX веке, высокая чувствительность к дефициту влаги) имеют региональный характер и подтверждают общую тенденцию к аридизации климата в Северном и Центральном Казахстане.

Важным аспектом является внедрение современных программных решений (TSAP, ARSTAN, COFECHA), которые позволяют минимизировать субъективные ошибки при датировке и стандартизации. Автоматизированные алгоритмы кросс-датировки и расчёт статистических параметров обеспечивают высокую воспроизводимость результатов, что критически важно для включения данных в международные базы (например, Международный банк древесных колец).

Заключение

Дендрохронологический метод является эффективным и объективным инструментом для оценки состояния лесных экосистем Северного Казахстана. Выполненные в рамках проекта ИРН AP25796027 исследования на территории ГНПП «Кокшетау» позволили построить пять локальных древесно-кольцевых хронологий, охватывающих период с 1813 по 2025 год, и подтвердить их высокое качество ($EPS > 0,88$). Полученные серии демонстрируют чёткий региональный климатический сигнал, что даёт возможность использовать их для реконструкции гидротермических условий прошлого и прогнозирования реакции лесов на будущие изменения климата.

Внедрение дендрохронологического подхода в систему экологического мониторинга позволит получать долговременные ряды данных, объективно отражающих динамику роста древостоев. Перспективным направлением является создание национальной базы древесно-кольцевых хронологий, объединяющей данные из различных лесных регионов Казахстана. Такая база станет основой для разработки адаптационных стратегий устойчивого лесопользования и позволит повысить научную обоснованность природоохранных решений в условиях глобальных климатических изменений.

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From Genome Editing to Synthetic Life: New Principles for Programmable Cellular Engineering

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Abstract

Programmable cellular engineering has emerged as a transformative paradigm in modern life sciences, bridging the gap between precise genome editing and the construction of synthetic biological systems. This article examines the conceptual and technological transition from conventional gene modification approaches toward the design of cells with programmable, adaptive, and potentially synthetic functionalities. It focuses on the integration of genome editing, genetic code expansion, synthetic regulatory circuits, and directed evolution as foundational tools for engineering biological systems with predictable behavior. Particular attention is given to how these strategies enable the reprogramming of cellular identity, the redesign of metabolic and signaling pathways, and the development of novel therapeutic platforms. The study further explores the implications of synthetic life concepts for biotechnology, regenerative medicine, immunotherapy, and biosecurity. By outlining new principles of controllability, modularity, evolvability, and biosafety, this work proposes a framework for the next generation of programmable cellular systems. The convergence of genome engineering and synthetic biology is thus presented not only as a technical progression, but as a fundamental shift in how life can be understood, designed, and applied.

Keywords

genome editing; synthetic life; programmable cellular engineering; synthetic biology; genetic code expansion; directed evolution; cellular reprogramming; genomic engineering; therapeutic design; biosafety

From Genetic Modification to Biological Programming

The history of modern biotechnology can be read as a gradual shift from the passive observation of living systems to their increasingly precise manipulation. Early molecular biology provided tools to identify genes, characterize their functions, and alter them one by one. However, the emergence of genome editing transformed this landscape by enabling targeted, efficient, and programmable intervention in the genetic architecture of cells. What was once a slow process of genetic modification has evolved into a sophisticated engineering discipline capable of rewriting genomic information, redesigning regulatory networks, and constructing new biological behaviors. In this context, programmable cellular engineering has emerged as a unifying framework that links genome editing, synthetic biology, directed evolution, and synthetic genomics into a common technological and conceptual enterprise (Doudna and Charpentier, 2014; Cameron et al., 2014).

The decisive turning point in this transition was the development of RNA-guided editing technologies, particularly CRISPR-Cas systems. These tools made site-specific DNA cleavage accessible, scalable, and adaptable across organisms, allowing researchers to move beyond static genetic changes toward dynamic control of gene function. Genome editing is now used not only to disrupt or repair genes, but also to regulate transcription, alter chromatin states, edit base pairs without double-strand breaks, and rewrite cellular memory. As a result, the genome is increasingly treated not simply as hereditary material, but as an editable substrate for biological design. This change in perspective has profound implications. A cell is no longer viewed solely as a naturally evolved unit, but also as an information-processing platform that can be programmed through modular genetic inputs and outputs (Jinek et al., 2012; Doudna and Charpentier, 2014; Jusiak et al., 2016).

At the same time, synthetic biology has pushed the field beyond editing existing genomes toward constructing systems with new organizational principles. Synthetic circuits, orthogonal translation systems, expanded genetic codes, and minimal genomes have collectively redefined the boundaries of what counts as a living system. Instead of merely correcting errors in nature, researchers are now asking whether cells can be designed with predictable logic, controllable adaptation, and novel biochemical capacities. This review addresses that transition: from genome editing as a tool of targeted intervention to synthetic life as a platform for programmable function. It argues that the convergence of editing, synthesis, and evolutionary design is establishing new principles of cellular engineering based on modularity, orthogonality, controllability, evolvability, and biosafety (Xiao and Schultz, 2016; Kitada et al., 2018; Hanczyc, 2020).

Genome Editing as the Foundation of Programmable Biology

Genome editing became the foundation of programmable biology because it replaced randomness with design. Classical mutagenesis and recombination approaches provided important insights into gene function, but they lacked precision and were poorly suited for scalable engineering. Programmable nucleases changed this by enabling targeted DNA cleavage at user-defined loci. Zinc-finger nucleases and TALENs were important milestones, yet CRISPR-Cas systems dramatically expanded the accessibility of editing because target recognition could be reprogrammed through guide RNA sequence rather than through complex protein redesign. This reduced the technical barrier to genome engineering and accelerated its adoption across microbiology, plant biology, mammalian systems, and translational medicine (Doudna and Charpentier, 2014).

The significance of CRISPR extends beyond its simplicity. It introduced a general design logic in which biological specificity can be computationally specified and then implemented in living cells. The original demonstration that Cas9 could be directed by RNA to cut chosen DNA sequences established a paradigm for molecular programmability that still defines the field today (Jinek et al., 2012). Since then, multiple derivative platforms have emerged. Catalytically inactive Cas proteins have been converted into programmable transcriptional regulators, epigenetic modifiers, chromatin imaging tools, and base editors. Prime editing further extended the concept by enabling precise sequence rewriting without the need for donor templates or double-strand breaks. These innovations collectively transformed genome editing from a repair technology into a broader language for writing instructions into cellular systems. Cells can now be directed to sense conditions, execute conditional responses, and store information in genetically encoded form (Jusiak et al., 2016; Ho and Chen, 2017).

Importantly, the engineering value of genome editing lies not only in precision but also in combinatorial capacity. Multiplex editing permits simultaneous modification of numerous loci, making it possible to redesign pathways, alter regulatory hierarchies, and generate complex phenotypes that depend on coordinated genomic change. This feature is essential for programmable cellular engineering because most useful behaviors are emergent rather than gene-

specific. Drug resistance, lineage differentiation, metabolic productivity, and immune response all depend on interacting networks rather than isolated genes. Therefore, the power of editing technologies is fully realized only when they are embedded within systems-level strategies. Genome editing provides the chassis-level capacity to modify cells, but programmability emerges when edits are integrated with circuit design, feedback regulation, and selection frameworks. In that sense, genome editing is best understood not as the endpoint of engineering, but as the enabling infrastructure for a broader synthetic biology of living systems (Nielsen and Keasling, 2016; Han et al., 2023).

From Genome Editing to Synthetic Life: New Principles for Programmable Cellular Engineering

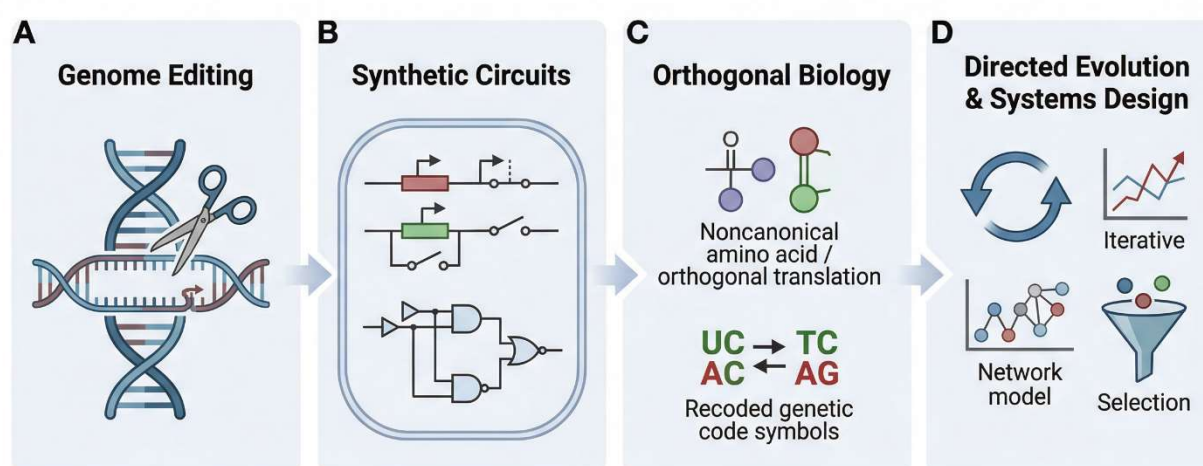


Figure 1. Conceptual framework of programmable cellular engineering. This schematic illustrates the transition from targeted genome editing to synthetic life as a continuum of increasing biological programmability. Genome editing provides the foundational capacity for precise modification of cellular DNA, while synthetic gene circuits introduce rule-based control over cellular decision-making. Genetic code expansion and orthogonal biology further extend cellular function by enabling new biochemical capabilities and reducing interference with native processes. Directed evolution and systems-level design then optimize these engineered functions under biological constraints. Together, these integrated approaches support the emergence of programmable cellular systems characterized by modularity, controllability, orthogonality, evolvability, and biosafety.

Synthetic Gene Circuits and the Logic of Cellular Decision-Making

A central ambition of programmable cellular engineering is to make cells behave as responsive, rule-governed systems rather than passive carriers of engineered genes. Synthetic gene circuits address this goal by translating engineering concepts such as logic gates, switches, oscillators, and feedback loops into biological form. These circuits are built from promoters, transcription factors, guide RNAs, recombinases, degradation tags, and signaling modules that interact to generate controlled outputs under defined conditions. In essence, synthetic circuits give cells a capacity for

decision-making. They allow engineered organisms to respond differently depending on environmental inputs, internal states, or combinations of molecular signals. This is a fundamental step in the transition from gene editing to programmable behavior (Purnick and Weiss, 2009; Jusiak et al., 2016).

CRISPR-based synthetic circuits significantly broadened this design space. Because nuclease-dead Cas proteins can be directed to chosen loci by RNA guides, they provide a modular means of controlling transcription without altering DNA sequence. This modularity has enabled the construction of layered regulatory networks in which multiple targets can be activated or repressed in parallel. Such systems are more scalable than earlier protein-based transcriptional regulators and can be redesigned with relative ease. CRISPR technologies have therefore become central to the construction of synthetic regulatory architectures in bacteria, yeast, and mammalian cells. The broader implication is that cells can increasingly be programmed with behaviors analogous to computational systems: sensing specific combinations of stimuli, filtering noise, computing thresholds, and switching among discrete phenotypic states (Jusiak et al., 2016; Ho and Chen, 2017).

The medical relevance of these circuits is especially notable. Synthetic biology has enabled the design of gene and cell therapies that activate only in diseased tissue, respond to inflammatory markers, or shut down through built-in safety switches. In engineered immune cells, for example, synthetic receptors and regulatory programs can improve specificity, reduce toxicity, and expand therapeutic control. Rather than simply editing a cell to express a therapeutic protein, researchers now aim to construct therapeutic systems that interpret context and adapt accordingly. This marks a shift from constitutive modification to conditional functionality. Programmability, in this sense, depends on information flow: cells must detect, process, and act on signals in ways that are robust yet tunable. Synthetic circuits supply the architecture for that information processing, making them one of the defining technologies in the move toward higher-order cellular engineering (Kitada et al., 2018; Cubillos-Ruiz et al., 2021). As circuit complexity grows, however, new design challenges arise, including crosstalk, metabolic burden, context dependence, and evolutionary instability, all of which must be addressed if programmable cells are to become reliable biomedical and industrial platforms.

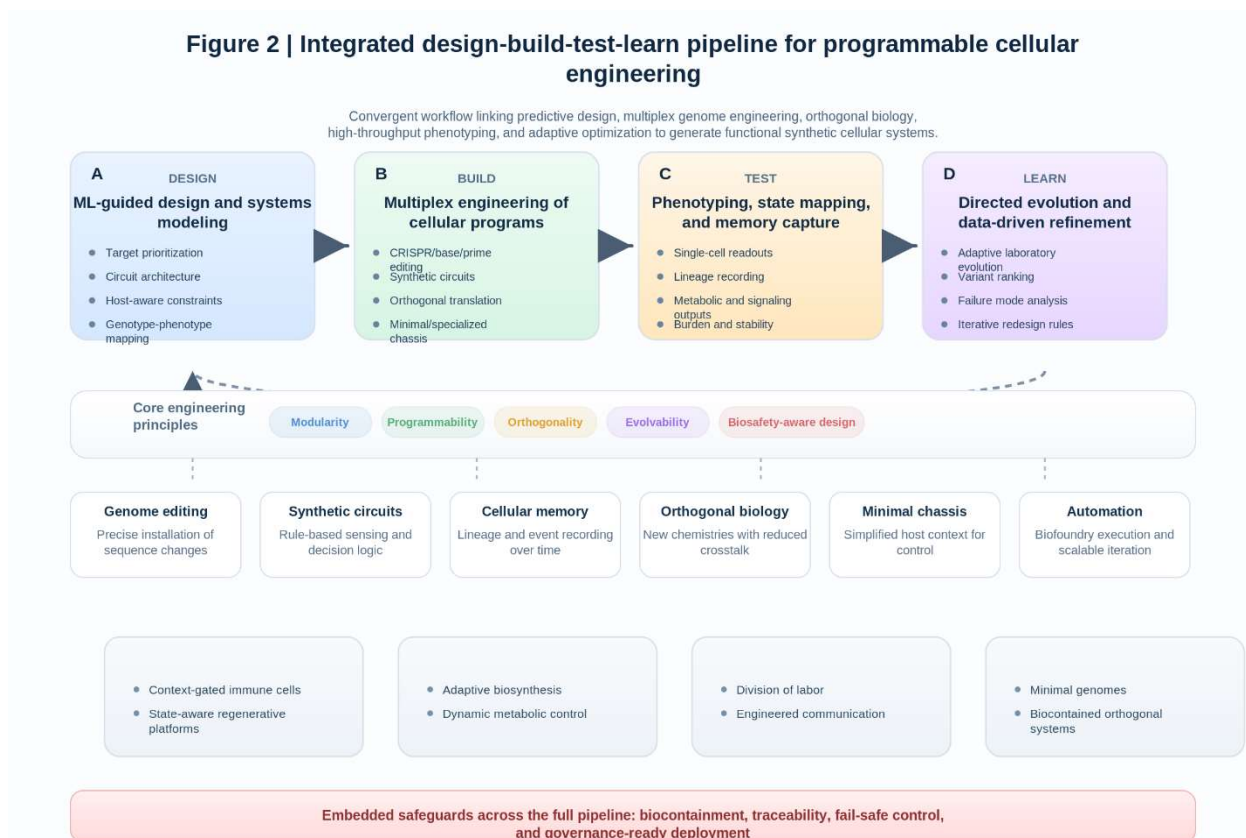


Figure 2. Integrated design-build-test-learn pipeline for programmable cellular engineering. This schematic summarizes a convergent workflow in which predictive design, genome-scale construction, systems-level testing, and adaptive optimization operate as a unified engineering cycle. In the design phase, machine learning, network modeling, and host-aware constraints prioritize targets, circuit architectures, and candidate chassis. The build phase implements these decisions through multiplex genome editing, synthetic regulatory circuits, orthogonal translation modules, and chassis minimization or specialization. The test phase captures function across multiple biological scales using high-throughput phenotyping, lineage recording, cellular memory systems, and measurements of burden and stability. The learn phase integrates these data with directed evolution and comparative analysis to identify high-performance variants and inform the next round of redesign. Across the pipeline, modularity, programmability, orthogonality, evolvability, and biosafety-aware design function as organizing principles rather than downstream considerations. The outputs include programmable therapeutic cells, adaptive microbial cell factories, cooperative multicellular systems, and synthetic or recoded life platforms. Together, these layers illustrate how programmable cellular engineering is shifting from isolated genetic modification toward predictive, iterative, and safety-integrated construction of functional living systems.

Cellular Reprogramming and the Engineering of Identity

One of the most powerful consequences of genome editing and synthetic regulation is the ability to reprogram cellular identity. Traditionally, cell identity was understood as a relatively stable outcome of developmental history, defined by transcriptional states, epigenetic landscapes, and lineage-specific regulatory networks. Advances in reprogramming biology challenged this view by showing that differentiated cells can be returned to pluripotency or converted directly into other cell types. Genome editing and synthetic biology have now extended this insight from developmental biology into engineering: cell identity can be designed, stabilized, redirected, or made conditional through programmable interventions in gene regulatory networks (Ho and Chen, 2017).

Cellular reprogramming depends on the manipulation of systems rather than single genes. Although transcription factors remain central, precise reprogramming increasingly involves editing enhancer landscapes, modulating chromatin accessibility, targeting noncoding regulatory elements, and tuning signal transduction pathways. CRISPR-based activators and repressors have proved especially valuable because they enable multiplex perturbation of endogenous regulatory networks while preserving genomic context. This allows researchers to interrogate and control the circuits that define fate decisions. In practical terms, such tools enable the construction of cells with desired developmental trajectories, functional states, or therapeutic properties. For regenerative medicine, this means more precise generation of transplantable cells. For cancer biology, it allows modeling of tumor initiation and lineage plasticity. For immunotherapy, it opens routes to reprogram effector function, persistence, and exhaustion resistance in engineered immune cells (Doudna and Charpentier, 2014; Kitada et al., 2018).

The concept of cellular identity as programmable also changes how disease is understood. Many diseases can be interpreted not merely as gene defects, but as failures of cellular state control. Fibrosis, cancer, autoimmunity, and neurodegeneration all involve inappropriate activation, loss of lineage fidelity, or maladaptive responses to signals. Programmable cellular engineering offers a way to intervene at the level of state regulation rather than isolated mutation correction. A therapeutic cell can be engineered not only to survive or secrete a factor, but to adopt specific response patterns in real time. Such an approach is inherently synthetic because it combines genetic editing, circuit logic, and systems control into a unified design strategy. The long-term significance is considerable: once identity is treated as an engineerable property, cells become substrates for rational redesign rather than fixed biological categories. This perspective brings programmable cellular engineering closer to the concept of synthetic life, where living systems are intentionally organized around human-defined functional goals rather than solely around naturally inherited forms (Kitada et al., 2018; Cubillos-Ruiz et al., 2021; Hanczyc, 2020).

Genetic Code Expansion and the Emergence of Orthogonal Biology

If genome editing allows the rewriting of natural biological information, genetic code expansion allows the creation of new information channels within living systems. This approach is based on the incorporation of noncanonical amino acids into proteins through engineered aminoacyl-tRNA synthetase/tRNA pairs that function orthogonally to the host translational machinery. By reassigning nonsense codons, frameshift codons, or even engineered codons, researchers have introduced new chemical functionalities into proteins in bacteria, yeast, and mammalian cells. This has enormous implications for programmable cellular engineering because it extends the biochemical repertoire of life beyond the canonical twenty amino acids (Xiao and Schultz, 2016). The importance of genetic code expansion lies not only in adding chemical novelty, but in creating partially independent biological layers. Orthogonal translation systems permit the execution of synthetic functions with reduced interference from endogenous pathways. In principle, such systems provide a route to biological compartmentalization at the informational level: one set of molecules can sustain native life functions, while another supports engineered behavior. This makes orthogonality one of the most important design principles in the path from genome editing to synthetic life. Orthogonal systems can reduce crosstalk, improve control, and create biochemical “firewalls” between natural and engineered processes. They also enable advanced applications such as photo-crosslinking, bioorthogonal labeling, control of protein stability, targeted drug conjugation, and the design of therapeutic proteins with enhanced or entirely novel properties (Xiao and Schultz, 2016; Shandell et al., 2021; Huang et al., 2024).

From a conceptual perspective, genetic code expansion challenges the long-standing assumption that the genetic code is fixed and universal. Synthetic biology instead treats it as an evolvable and engineerable standard. This has direct relevance to synthetic life because the code defines the

translation of information into function. Altering that code, even partially, begins to establish biological systems with distinct rules of molecular interpretation. Such systems could eventually support forms of biochemical organization that differ in meaningful ways from naturally evolved cells. Moreover, code expansion intersects with therapeutic design. Engineered proteins with site-specific modifications can improve targeting, pharmacokinetics, controllable activation, and immune compatibility. Thus, orthogonal biology is not a speculative fringe of the field; it is already contributing to medicine and biotechnology. As programmable cellular engineering matures, genetic code expansion may become one of its most powerful pillars, linking information engineering with functional innovation and biosafety-oriented separation between synthetic and natural biology (Shandell et al., 2021; Huang et al., 2024).

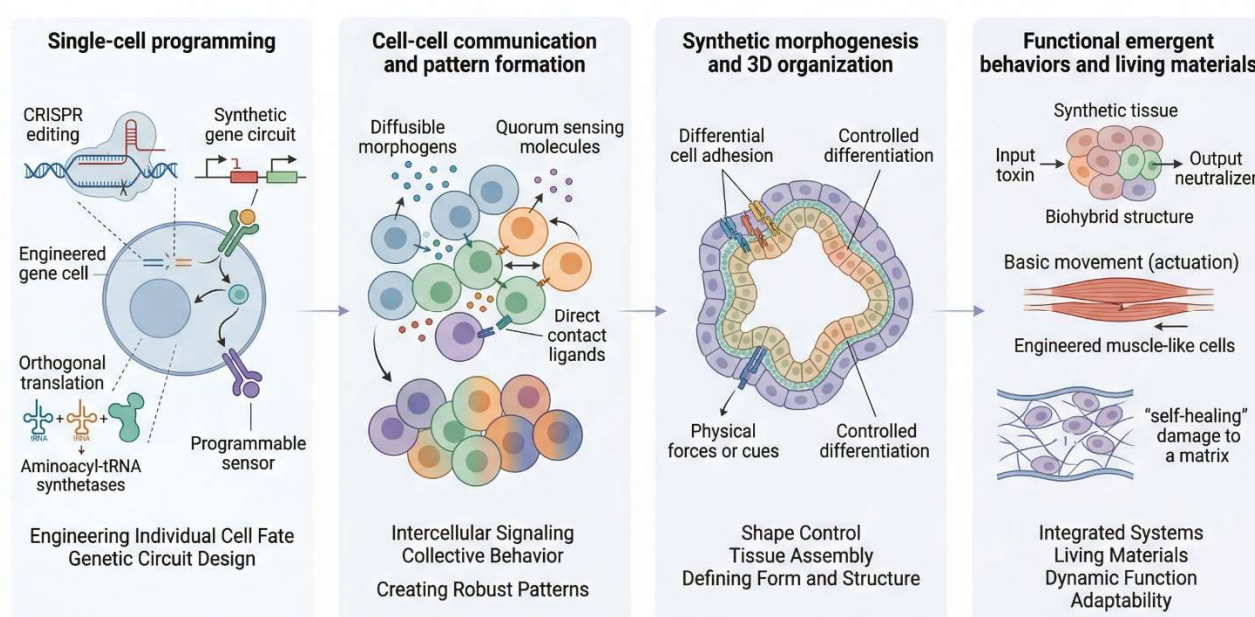


Figure 3. Multicellular engineering and synthetic morphogenesis as the next stage of programmable cellular engineering.

This schematic illustrates the transition from single-cell engineering to higher-order programmable biological organization. The left panel shows individual cells equipped with genome editing, synthetic regulatory circuitry, orthogonal functional modules, and programmable sensing capabilities. The second panel depicts engineered cell–cell communication through diffusible signals, receptor-mediated recognition, and feedback control, enabling coordinated information exchange across populations. The third panel presents cooperative division of labor, in which specialized cellular subpopulations function as sensors, processors, effectors, and producers within distributed consortia or tissue-like assemblies. The right panel represents synthetic morphogenesis, where controlled signaling, spatial gradients, and differentiation programs drive the emergence of organized multicellular architectures. Together, these stages reflect a progression from molecular programmability to collective biological design, guided by the principles of modularity, orthogonality, evolvability, and biosafety-aware engineering.

Directed Evolution and the Limits of Rational Design

Although programmable cellular engineering is often described in terms of rational design, biological complexity quickly exposes the limits of purely deterministic approaches. Living systems contain nonlinear interactions, hidden constraints, emergent behaviors, and context-dependent effects that cannot always be predicted from sequence or structure alone. Directed evolution addresses this challenge by complementing design with iterative selection. Instead of requiring complete mechanistic understanding in advance, it uses variation and screening to identify functional solutions that would be difficult to anticipate. For this reason, directed evolution has become an indispensable partner to synthetic biology and a critical element in the development of programmable cells (Cobb et al., 2012; Currin et al., 2015).

The value of directed evolution is evident across multiple scales. At the protein level, it can improve catalytic activity, substrate specificity, stability, and regulatory responsiveness. At the pathway level, it can optimize metabolic flux and rebalance enzyme expression. At the network level, it can tune dynamic behavior, reduce noise, and improve switching performance. At the whole-cell level, it can produce complex phenotypes such as stress resistance, altered morphology, or enhanced production traits. This multiscale applicability makes directed evolution uniquely compatible with programmable cellular engineering, which also operates across levels of organization. Rational design specifies the intended function; evolution explores the feasible routes by which biology can actually implement it (Cobb et al., 2012; Wang et al., 2021).

Importantly, directed evolution is not opposed to programmability. On the contrary, it expands it. A fully programmable engineering platform must be able not only to install designed functions, but also to refine them under realistic biological constraints. Evolutionary methods help bridge the gap between conceptual design and operational performance. They are particularly useful when engineering new receptors, switches, sensors, transcription factors, enzymes, or translation components that must function within crowded intracellular environments. Directed evolution also plays a key role in expanding the design space of synthetic biology beyond what natural proteins and pathways readily permit. In this sense, it is a method for discovering biological implementations of human design goals. The future of programmable cellular engineering will likely depend on integrated workflows in which computational design, genome editing, high-throughput screening, and machine-guided evolution operate as a single pipeline. Such convergence would move the field closer to true biological engineering, where cells are not only modified but iteratively optimized as adaptive systems (Currin et al., 2015; Wang et al., 2021). The rise of automated evolution platforms and large-scale genotype–phenotype mapping further supports this trajectory, making it increasingly feasible to engineer function at levels that were once beyond rational prediction.

Minimal Genomes, Synthetic Cells, and the Threshold of Synthetic Life

The movement from programmable cellular engineering to synthetic life becomes most visible in efforts to define, construct, and minimize living systems. Synthetic genomics has demonstrated that whole genomes can be designed digitally, assembled chemically, and installed into recipient cells to produce viable organisms. A landmark achievement in this area was the creation of a bacterial cell controlled by a chemically synthesized genome, proving that genomic information could be manufactured and still direct cellular life processes (Gibson et al., 2010). This result was conceptually transformative because it separated the informational identity of the cell from its historical biological origin. Life, at least in part, could be specified as a designed sequence.

Minimal genome research pushed this idea further by asking which genes are truly required for cellular viability under defined conditions. The synthesis of a minimal bacterial genome revealed that a surprisingly small set of genes can support life, while also showing that many essential

functions remain incompletely understood even in stripped-down systems (Hutchison et al., 2016). This finding is important for programmable engineering for two reasons. First, minimal cells can serve as simplified chassis with reduced background complexity, making synthetic functions easier to predict and control. Second, the process of minimization exposes the deep interdependence of cellular processes, reminding engineers that life is not a sum of independent modules but a tightly coupled system.

The threshold between engineered cells and synthetic life is not defined by a single event, but by a gradual increase in design authorship. A cell becomes more “synthetic” as its genome, regulatory architecture, translation machinery, and environmental dependencies are increasingly specified by design rather than inherited from nature. Yet synthetic life does not require complete *de novo* creation. Partial synthesis, orthogonal subsystems, recoded genomes, and artificial compartments all contribute to a spectrum of syntheticity. What matters scientifically is the extent to which biological behavior can be intentionally organized around human-defined principles. Minimal genomes and synthetic cells therefore serve as experimental platforms for understanding life by rebuilding it. They also provide a testbed for biosafety strategies, chassis optimization, and orthogonal module integration. In this respect, synthetic life should be understood not merely as an ultimate technological goal, but as a research framework for discovering the design principles that make biological systems controllable, evolvable, and functional (Gibson et al., 2010; Hutchison et al., 2016; Hanczyc, 2020).

Therapeutic Applications of Programmable Cellular Engineering

The clinical significance of programmable cellular engineering lies in its ability to move beyond static therapies toward dynamic therapeutic systems. Traditional biologics and small molecules often act in fixed ways once delivered, regardless of changing physiological context. Engineered cells, by contrast, can be designed to sense, decide, and respond within the body. This capability is particularly important in oncology, immunology, regenerative medicine, and metabolic disease, where therapeutic efficacy often depends on temporal control, tissue specificity, and adaptive behavior. Synthetic biology has therefore shifted attention from simply correcting genes to constructing living therapeutics with programmable functions (Kitada et al., 2018; Cubillos-Ruiz et al., 2021).

One major application area is engineered immune cell therapy. Genome editing is already used to improve immune cell persistence, remove inhibitory receptors, reduce alloreactivity, and enhance tumor targeting. Synthetic circuit design adds an additional layer by enabling context-dependent activation, combinatorial antigen recognition, and fail-safe shutdown systems. Such approaches aim to improve the therapeutic index of cell therapies by increasing precision while reducing off-target toxicity. Similar principles are being applied to stem cells, microbial therapeutics, and tissue-resident engineered cells. In these systems, cells are programmed not merely to survive transplantation, but to execute defined therapeutic tasks under physiologically relevant conditions. This represents a major conceptual change in medicine: therapy becomes an embedded biological process rather than an external intervention (Kitada et al., 2018; Cubillos-Ruiz et al., 2021).

Genetic code expansion and orthogonal biology may further broaden therapeutic design by enabling proteins with non-natural functions, controllable conjugation chemistries, and novel drug delivery properties. Meanwhile, genome-scale editing and synthetic reprogramming are making it possible to construct disease models with unprecedented precision, thereby accelerating drug discovery and personalized therapy development. Even in industrial and environmental biotechnology, programmable cells are being engineered to produce pharmaceuticals, diagnose disease states, and respond to chemical or metabolic cues in real time. The common principle across these examples is functional programmability: cells are designed to enact rules, not merely express traits. As this field advances, the distinction between therapy and device may become

increasingly blurred. A living therapeutic is both a biological entity and an engineered control system. For that reason, programmable cellular engineering should be seen as one of the most important platforms for next-generation biomedicine, with implications that extend far beyond gene correction alone (Nielsen and Keasling, 2016; Cubillos-Ruiz et al., 2021; Yan et al., 2023).

Biosafety, Biocontainment, and Ethical Design Principles

As cells become more programmable, powerful, and autonomous, biosafety and biosecurity move from peripheral concerns to central design requirements. Engineering cells to perform novel functions inevitably raises questions about containment, predictability, misuse, ecological impact, and governance. This is especially true when dealing with self-replicating systems, synthetic genomes, expanded genetic codes, or engineered organisms intended for therapeutic or environmental release. In such contexts, safety cannot be treated as an afterthought. It must be integrated into the architecture of engineered systems from the beginning, consistent with the principle of safety by design (Wright et al., 2013; Hoffmann et al., 2023).

Biocontainment strategies have evolved from physical barriers toward intrinsic genetic safeguards. Existing approaches include auxotrophic dependencies, toxin–antitoxin modules, kill switches, conditional replication systems, and control of essential genes through inducible mechanisms. These methods aim to reduce the probability that engineered organisms persist or spread outside intended environments. More advanced concepts involve orthogonal translation systems, recoded genomes, and alternative nucleic acid chemistries, which may create stronger firewalls between synthetic and natural biology. Such strategies are particularly relevant in the era of synthetic genomics because they reduce not only ecological risk but also the likelihood of horizontal gene transfer or unintended evolutionary escape (Wright et al., 2013; Hoffmann et al., 2023).

At the same time, biosafety cannot be reduced to organism-level design alone. Digital sequence screening, order verification, institutional oversight, international governance, and transparent risk assessment are also essential. The growing accessibility of DNA synthesis and genome engineering increases the need for coordinated safeguards that operate across the entire design-build-test-deploy pipeline. Ethical design in programmable cellular engineering therefore involves multiple commitments: minimizing harm, increasing traceability, maintaining reversibility where possible, and ensuring that system complexity does not outstrip our capacity for oversight. There is also a broader philosophical issue. As biology becomes engineerable, the distinction between creating knowledge and creating capability becomes less clear. This means that responsibility must be distributed across scientists, institutions, funders, companies, and regulators alike. The future of synthetic life research will depend not only on technical success, but on whether robust cultures of responsibility can keep pace with accelerating capability (Schmidt, 2008; Wright et al., 2013; Hoffmann et al., 2023).

New Principles for the Future of Programmable Cellular Engineering

The transition from genome editing to synthetic life is not simply the accumulation of new techniques; it reflects the emergence of a new engineering logic for living systems. Several principles now appear fundamental. The first is modularity, the ability to decompose biological function into semi-independent units such as sensors, actuators, switches, pathways, and orthogonal subsystems. The second is programmability, meaning that desired functions can be specified in advance and implemented through editable molecular instructions. The third is orthogonality, which reduces interference between engineered and endogenous processes and thereby increases reliability. The fourth is evolvability, recognizing that robust biological engineering must account for adaptation and use it productively through selection and iterative refinement. The fifth is biosafety-aware design, in which containment and governance are built

into systems rather than imposed only externally (Kitada et al., 2018; Cubillos-Ruiz et al., 2021; Hoffmann et al., 2023).

These principles suggest that future cellular engineering will be defined less by individual platforms and more by convergent workflows. Genome editing will provide precise installation of changes; synthetic circuits will govern information processing; expanded genetic codes will introduce new chemistries; minimal genomes will simplify chassis behavior; and directed evolution will optimize performance under biological constraints. Increasingly, these layers are being linked to computational design, machine learning, automated screening, and high-throughput phenotyping. The result is a shift from artisanal bioengineering toward a more integrated discipline in which cells are designed, tested, and refined as programmable systems. This does not imply complete predictability. Biology will remain context-sensitive and historically contingent. But the field is steadily improving its ability to impose functional order on that complexity (Nielsen and Keasling, 2016; Wang et al., 2021).

Ultimately, synthetic life should not be understood only as the artificial creation of living matter, but as the establishment of design principles that make life increasingly engineerable. In this broader sense, programmable cellular engineering is already a form of synthetic life research because it seeks to define the rules by which cells can be made controllable, useful, and safe under human direction. The future challenges are therefore both scientific and philosophical: how far can biological systems be redesigned without losing robustness, how should synthetic and natural systems be separated or integrated, and what kinds of life should be built at all? These questions will shape the next phase of the field. What is already clear, however, is that genome editing opened the door, synthetic biology widened it, and programmable cellular engineering is now carrying the life sciences across a threshold into a fundamentally new era of biological design (Doudna and Charpentier, 2014; Hanczyc, 2020; Huang et al., 2024).

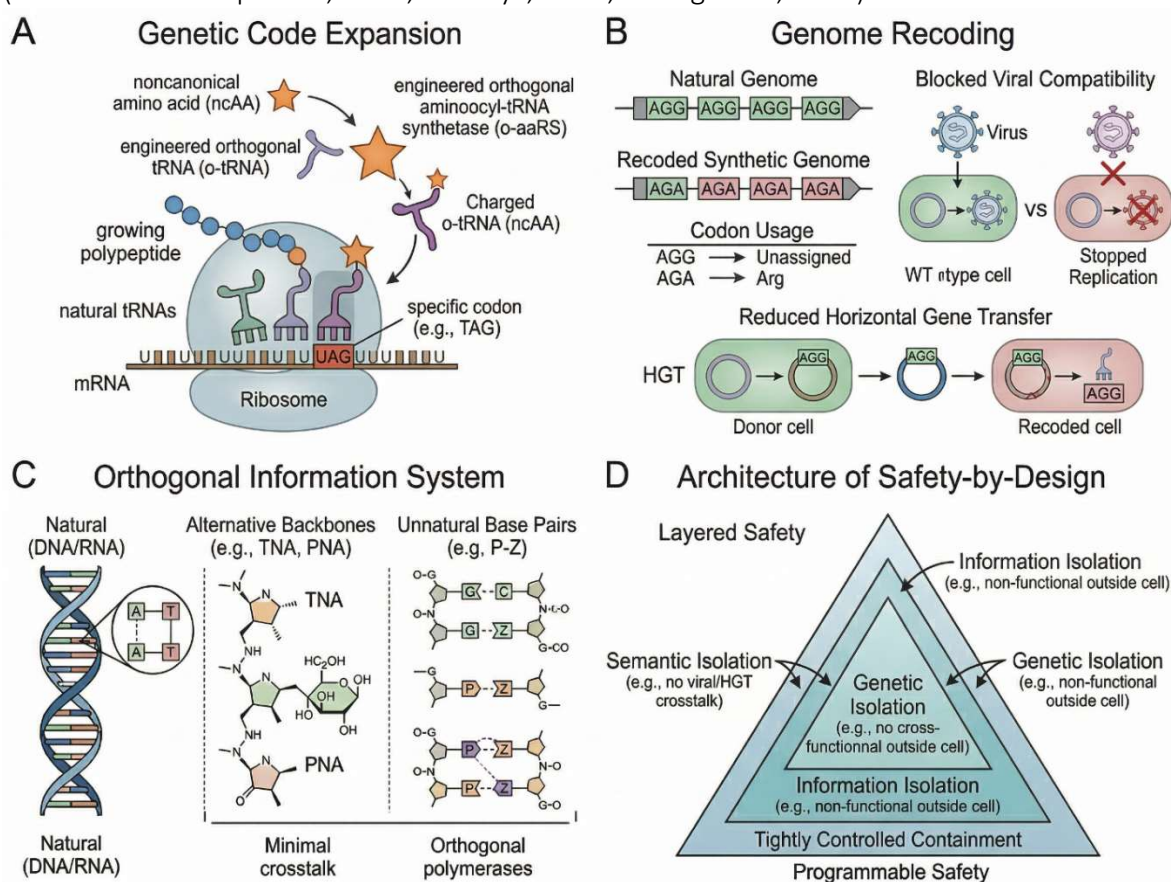


Figure 4. Orthogonal biology and the architecture of safety-by-design in programmable cellular engineering. This schematic illustrates how orthogonal biological systems extend programmable

cellular engineering beyond conventional genome editing. (A) Genetic code expansion enables site-specific incorporation of noncanonical amino acids through engineered orthogonal translation machinery. (B) Genome recoding establishes altered codon usage and reduced compatibility with natural viral and horizontal gene transfer pathways. (C) Alternative informational systems, including orthogonal nucleic acid or translation layers, create biochemical separation between synthetic and native cellular processes. (D) Integrated biocontainment modules, including synthetic auxotrophy and inducible kill switches, support biosafety by restricting survival and propagation outside defined environments. Together, these strategies show how programmable cells can acquire novel function while maintaining controllability, orthogonality, and ecological containment

Systems Biology, Modeling, and the Rise of Predictive Design

Programmable cellular engineering cannot advance on experimental power alone; it also depends on the ability to predict how engineered changes will behave within complex living systems. This is where systems biology becomes indispensable. While genome editing and synthetic biology provide tools for intervention, systems biology provides the conceptual and computational framework necessary to understand cellular networks as dynamic, interacting wholes. Genes, proteins, metabolites, and regulatory RNAs do not operate in isolation. Their behavior depends on nonlinear interactions, feedback loops, stochastic fluctuations, spatial constraints, and environmental conditions. As a result, the design of programmable cells increasingly requires quantitative models capable of integrating multiple layers of biological organization (Kitano, 2002; Nielsen and Keasling, 2016).

The role of modeling in cellular engineering has evolved from descriptive analysis to active design support. Early systems biology emphasized mapping pathways and measuring network structure, but contemporary approaches increasingly seek to forecast the consequences of intervention. Mathematical models, constraint-based simulations, gene regulatory network inference, and multi-omics integration are now used to identify bottlenecks, predict off-target effects, and optimize circuit behavior before experimental implementation. In metabolic engineering, for example, flux balance analysis has helped prioritize gene targets and pathway architectures for product synthesis. In synthetic circuit design, kinetic modeling assists in tuning promoters, degradation rates, and feedback strength. In mammalian engineering, systems-level datasets are being used to understand how edited cells respond to stress, signaling, or immune pressure. These capabilities make programmable biology more rational, more scalable, and more reproducible (Nielsen and Keasling, 2016; Han et al., 2023).

However, predictive design in biology faces intrinsic limits. Unlike many classical engineering materials, cells evolve, vary from one another, and change state over time. The same genetic construct may behave differently in distinct hosts or under altered physiological conditions. Context dependence remains one of the defining obstacles to robust design. Therefore, predictive engineering must be probabilistic rather than purely deterministic. Models should not aim to eliminate uncertainty entirely, but to reduce it sufficiently for useful intervention. This has led to hybrid strategies in which computation guides initial design, experimentation tests behavior, and iterative redesign refines function. Such cycles mirror the logic of other mature engineering disciplines, but they are adapted to the variability of living matter. The long-term promise is substantial: as predictive frameworks improve, programmable cellular engineering may transition from empirical craft toward a more disciplined science of biological design, in which network-aware modeling becomes as important as molecular editing itself (Cameron et al., 2014; Wang et al., 2021). In this sense, systems biology is not merely supportive infrastructure; it is one of the intellectual foundations of programmable life, because it turns biological complexity from an obstacle into an engineerable design space.

Multiplex Editing, Lineage Recording, and Cellular Memory

One of the defining advantages of programmable cellular engineering is its capacity to act on many genomic sites simultaneously and to use the genome not only as a target of change but also as a medium for information storage. Multiplex editing has made it possible to redesign pathways, modify regulatory architectures, and generate combinatorial phenotypes at scales that were previously impractical. This matters because most useful cellular functions arise from distributed networks rather than single genes. Whether the objective is enhanced metabolite production, immune-cell optimization, developmental reprogramming, or stress tolerance, desired behaviors usually depend on coordinated manipulation of multiple loci. Multiplex CRISPR systems therefore represent a major step toward cells that can be comprehensively programmed rather than incrementally modified (Doudna and Charpentier, 2014; Han et al., 2023).

The significance of multiplexing becomes even greater when it is combined with cellular memory. A programmable cell should ideally not only execute responses but also record information about what it has experienced. Recent advances in CRISPR-based recording, recombinase logic, and genomic barcoding suggest that cells can function as biological memory devices. Signals such as inflammation, developmental cues, or environmental exposures can be translated into stable DNA changes, enabling later reconstruction of cellular histories. In developmental biology, lineage-tracing methods based on evolving genetic barcodes have made it possible to map cell ancestry with unprecedented resolution. In synthetic biology, similar concepts are being adapted to create cells that log events, count exposures, or switch permanently into new states after defined inputs. Such capabilities expand programmability from immediate response to historical computation, allowing cells to integrate information over time rather than merely reacting in the moment (Jusiak et al., 2016; Ho and Chen, 2017).

Cellular memory has profound practical implications. In medicine, engineered cells could record exposure to tumor markers, inflammatory cytokines, or tissue-specific conditions, thereby improving diagnosis and therapeutic monitoring. In industrial microbiology, cells could be designed to track metabolic stress or nutrient limitation during bioprocessing. In basic research, programmable memory systems can provide a powerful means to study transient biological events that are otherwise difficult to capture. Yet these advances also raise design challenges. Memory systems must be stable, minimally disruptive, and interpretable across heterogeneous populations. They must avoid excessive mutation burden while preserving signal fidelity. Despite these constraints, the broader importance is clear: the programmable cell is increasingly becoming an informational entity capable of sensing, storing, and acting on experience. This transforms the genome from a passive blueprint into an editable and writable substrate for biological computation. In that respect, multiplex editing and cellular memory bring engineering closer to one of the deepest ambitions of synthetic biology: creating living systems that not only function according to design, but also accumulate history in designed ways (Kitada et al., 2018; Wang et al., 2021).

Metabolic Engineering and Programmable Microbial Cell Factories

Among the most mature applications of programmable cellular engineering is the redesign of cellular metabolism for industrial and biomedical production. Metabolic engineering began as the targeted improvement of biosynthetic pathways, but it has increasingly merged with synthetic biology, systems biology, and genome editing into a comprehensive framework for programming microbial function. Microbial cells are now routinely engineered to produce fuels, pharmaceuticals, fine chemicals, food ingredients, and biomaterials. What distinguishes contemporary approaches from earlier efforts is the degree of control that can be exerted over pathway composition, gene dosage, regulation, and host physiology. Rather than inserting a few

heterologous enzymes, engineers now seek to build coordinated metabolic systems whose behavior is dynamically optimized within living cells (Nielsen and Keasling, 2016).

Programmability is especially important in metabolism because biosynthetic pathways are deeply integrated into the cellular economy. Productivity depends not only on pathway presence, but also on flux balance, cofactor availability, redox state, toxicity management, and stress response. Genome editing enables the deletion of competing pathways, modulation of transporter activity, and fine-tuning of native regulation. Synthetic circuits allow metabolic pathways to be linked to biosensors and feedback controllers, so that production can be adjusted automatically in response to internal metabolite concentrations or environmental conditions. Directed evolution can then refine enzyme performance and strain robustness when rational prediction proves insufficient. This combination of editing, sensing, and adaptation makes microbial cell factories a particularly clear example of how programmable cellular engineering operates in practice (Cobb et al., 2012; Nielsen and Keasling, 2016; Han et al., 2023).

The broader relevance of microbial engineering extends beyond manufacturing efficiency. Microbes serve as model platforms for testing general principles of programmability, orthogonality, and biosafety. Because they grow rapidly and are experimentally tractable, they allow synthetic designs to be iterated quickly and evaluated across many generations. Lessons learned in microbial systems often inform later work in mammalian and multicellular contexts. At the same time, engineered microbes are increasingly being deployed in applications that blur the line between industry and medicine, including probiotic therapeutics, biosensors, and living materials. This expansion underscores an important point: programmable metabolism is not merely about maximizing product titers. It is about turning cells into responsive biochemical devices whose outputs can be modulated in time and space. As the field advances, microbial chassis may become increasingly specialized, with minimal genomes, orthogonal pathways, and encoded containment features tailored to particular tasks. In that sense, microbial cell factories are not just tools of biotechnology; they are early prototypes of synthetic living systems organized around human-defined functional objectives (Bassalo et al., 2016; Cubillos-Ruiz et al., 2021; Yan et al., 2023).

Multicellular Engineering and the Design of Cooperative Systems

Although much of programmable cellular engineering has been developed at the single-cell level, many of the most important biological and biomedical functions are inherently multicellular. Tissues, immune responses, developmental processes, and microbial communities all emerge from communication among interacting cells rather than from isolated intracellular programs. As a result, synthetic biology is increasingly concerned with engineering not only cellular behavior, but also collective behavior. Multicellular engineering seeks to control how cells signal to one another, divide labor, establish spatial organization, and coordinate decisions across populations. This transition is crucial if programmable biology is to move from simple engineered organisms toward tissue-like systems and synthetic ecologies (Cameron et al., 2014; Kitada et al., 2018).

Cell-to-cell communication provides the foundation for such designs. In bacteria, quorum-sensing modules have long served as tools for coordinating gene expression across populations. In mammalian systems, synthetic receptors, cytokine programs, ligand–receptor pairs, and contact-dependent signaling circuits are now being used to regulate population-level behavior. These approaches allow engineered cells to communicate state information, trigger collective responses, and partition functional roles across subpopulations. For example, one cell type may act as a sensor, another as a processor, and a third as an effector. Such division of labor can increase robustness and reduce the burden placed on any single cell type. It also creates opportunities for emergent behavior, in which the engineered system performs tasks that no individual cell could achieve alone (Purnick and Weiss, 2009; Kitada et al., 2018).

The ability to engineer cooperation has major implications for regenerative medicine, immunotherapy, and living materials. In tissue engineering, synthetic signaling programs may help control cell differentiation, organization, and repair processes within complex environments. In cancer therapy, cooperative cell systems could distribute sensing and killing functions across immune and stromal compartments. In microbial consortia, engineered communities may outperform monocultures in stability, resource use, and environmental responsiveness. Yet multicellular engineering also introduces new complexities, including spatial heterogeneity, communication noise, competition, and ecological instability. Engineering success therefore depends not only on intracellular programming but also on the design of intercellular relationships. The programmable unit of biology is expanding from the cell to the collective. This is a profound conceptual step. It suggests that synthetic life will not necessarily be defined only by artificially altered cells, but by designed biological societies in which function arises through structured cooperation. In this emerging framework, multicellularity becomes an engineerable property rather than merely a product of evolution, opening new possibilities for the deliberate construction of complex living systems (Cameron et al., 2014; Cubillos-Ruiz et al., 2021; Hanczyc, 2020).

Synthetic Morphogenesis and the Engineering of Biological Form

If programmable cellular engineering seeks to control biological function, a natural next step is to control biological form. Morphogenesis—the process by which cells generate organized structures during development—has traditionally been studied as an emergent property of natural systems. Synthetic biology is now beginning to ask whether morphogenesis itself can be engineered. This field, sometimes described as synthetic morphogenesis, aims to program the spatial arrangement of cells, the patterning of tissues, and the emergence of form through designed genetic and signaling circuits. Such efforts represent a major expansion in ambition: rather than merely changing what cells do, engineers are attempting to direct how they organize in space and time (Davies, 2008; Cameron et al., 2014).

Synthetic morphogenesis depends on integrating intracellular programming with intercellular communication and biomechanical constraints. Pattern formation can be influenced by engineered gradients, reaction–diffusion mechanisms, adhesion molecules, differentiation switches, and mechanical feedback loops. Cells may be programmed to sort into defined structures, polarize in response to cues, or differentiate according to local neighborhood composition. In organoid biology and tissue engineering, these ideas are increasingly relevant because functional tissues require not only the correct cell types, but also the correct architecture. A liver, intestine, or neural organoid is not merely a collection of differentiated cells; it is a spatially organized system in which geometry and signaling jointly define function. Synthetic approaches therefore seek to harness developmental rules as engineerable modules rather than opaque natural processes (Ho and Chen, 2017).

The implications of this work extend far beyond tissue fabrication. Synthetic morphogenesis provides a route to understanding developmental biology by reconstruction, much as minimal genomes provide insight into life by simplification. It also raises the possibility that the form of living systems can become a direct design target. Living materials with self-repairing architectures, programmable tissues for regenerative medicine, and model systems for developmental disorders all lie within this conceptual horizon. Nevertheless, engineering form is especially challenging because spatial patterning amplifies the effects of noise, heterogeneity, and environmental context. Genetic designs that function predictably in single cells may behave unpredictably when coupled to adhesion, migration, proliferation, and mechanics. Thus, synthetic morphogenesis will require genuinely integrative engineering that spans molecular, cellular, and physical scales. Even so, its emergence signals an important evolution in the field: programmable cellular engineering is no longer limited to the regulation of molecular outputs, but is beginning to encompass the

deliberate design of living structure itself. In that sense, engineering biological form may become one of the clearest indicators that synthetic biology has moved from genome editing toward a broader science of synthetic life (Davies, 2008; Hanczyc, 2020; Yan et al., 2023).

Xenobiology, Genome Recoding, and Alternative Rules of Life

A particularly radical branch of programmable cellular engineering is xenobiology, which explores whether life can be built on chemical and informational rules that differ from those used by natural organisms. While conventional synthetic biology typically modifies existing systems, xenobiology seeks to create forms of biological organization that are partly separated from the natural biosphere by orthogonal molecular logic. This can involve recoded genomes, noncanonical amino acids, alternative base-pair systems, xeno nucleic acids, and expanded translation machinery. Such work is important not only because it broadens the chemistry of life, but because it challenges assumptions about universality in biological systems (Schmidt, 2010; Xiao and Schultz, 2016).

Genome recoding is one of the clearest examples of this shift. By systematically altering codon usage across the genome, researchers can free codons for reassignment, create resistance to viral infection, or establish translational dependence on engineered components. These changes have both practical and conceptual significance. Practically, recoded organisms can provide improved biosafety through reduced horizontal compatibility with natural systems. Conceptually, they reveal that the genetic code is not a fixed endpoint of biological evolution but a contingent standard that can be redesigned. Genetic code expansion operates within this same general logic, but genome-wide recoding extends it to the level of cellular identity. A cell whose translation system follows altered rules occupies a different informational niche from its natural counterpart, even if it remains recognizably biological (Shandell et al., 2021; Huang et al., 2024).

Xenobiology also intersects with questions of containment and governance. Orthogonal systems may function as powerful biosafety tools because they reduce the likelihood that synthetic genes will propagate through natural ecosystems. However, such systems also raise philosophical and regulatory questions about what counts as life, nature, and biological risk. The more independent synthetic organisms become from the existing biosphere, the more difficult it may be to evaluate their long-term ecological behavior using familiar frameworks. Yet this very independence is also what makes xenobiology attractive as a platform for safe and controllable engineering. It suggests a future in which engineered cells can be powerful without being fully interoperable with natural life. That prospect may prove essential for applications involving environmental release, advanced therapeutics, or large-scale manufacturing. More broadly, xenobiology exemplifies the deepest ambition of programmable cellular engineering: not simply to edit life as it exists, but to explore how life might be organized under alternative rules. In doing so, it transforms synthetic biology from a toolkit into an experimental philosophy of biological possibility (Schmidt, 2010; Wright et al., 2013; Huang et al., 2024).

Host–Circuit Interactions, Burden, and Evolutionary Stability

A recurring challenge in programmable cellular engineering is that synthetic constructs do not operate in empty space; they function within living hosts that possess their own priorities, constraints, and adaptive responses. This creates a fundamental tension between engineered function and cellular physiology. Synthetic circuits compete for transcriptional, translational, metabolic, and energetic resources. They may trigger stress responses, interfere with endogenous regulation, or impose growth defects that favor the emergence of escape mutants. Consequently, one of the most important lessons of modern synthetic biology is that successful engineering depends not only on the design of circuits themselves, but also on their relationship to the host cell (Purnick and Weiss, 2009; Cameron et al., 2014).

This issue is often described in terms of burden and context dependence. Burden refers to the physiological cost imposed by engineered functions, while context dependence reflects the fact that the same construct may behave differently in different hosts or conditions. These phenomena are major barriers to predictability and scalability. A circuit that performs well in one laboratory strain may fail in a production strain or therapeutic setting. Likewise, an engineered receptor or gene network may become unstable under long-term selection because cells that silence or delete the construct enjoy a fitness advantage. Evolutionary instability is therefore not a peripheral problem but a central design constraint, especially for applications that require prolonged function, large population sizes, or variable environments (Cobb et al., 2012; Wang et al., 2021). Several strategies have emerged to address these limitations. One is to reduce burden through more efficient part design, lower expression load, and dynamic control systems that activate functions only when needed. Another is to use genome integration rather than plasmid-based expression, thereby improving stability and reducing copy-number variability. Orthogonal systems may also help by separating synthetic resource use from endogenous pathways. Directed evolution and adaptive laboratory evolution can identify host backgrounds that better tolerate engineered functions, while systems-level measurements can reveal stress bottlenecks before they become catastrophic. Importantly, these approaches imply a shift in engineering philosophy. Instead of treating the host as a passive chassis, synthetic biology increasingly recognizes it as an active participant in design. The engineered phenotype emerges from negotiation between the circuit and the cell. A mature discipline of programmable cellular engineering must therefore include host-aware design principles that balance functionality, fitness, and long-term stability. Without such principles, increasingly sophisticated designs may remain fragile prototypes rather than reliable technologies. In this sense, understanding host–circuit interactions is as essential to the future of synthetic life as any advance in editing or synthesis, because it determines whether designed functions can persist within the reality of living systems (Cameron et al., 2014; Han et al., 2023).

Automation, Machine Learning, and the Biofoundry Paradigm

As programmable cellular engineering becomes more complex, the scale of experimentation required to design, test, and optimize living systems exceeds what traditional laboratory workflows can easily support. This has led to the rise of automation-driven biological engineering, often organized around the biofoundry model. Biofoundries integrate robotic assembly, high-throughput screening, standardized workflows, data capture, and computational design into iterative design–build–test–learn cycles. Their emergence reflects a broader transformation in the field: biology is increasingly being treated not merely as an experimental science, but as an engineering domain that can benefit from automation, reproducibility, and large-scale optimization (Hillson et al., 2019).

Automation is particularly valuable because biological design spaces are vast and combinatorial. Even relatively simple tasks, such as optimizing promoter strength, pathway stoichiometry, or guide RNA combinations, can generate thousands of plausible variants. Machine learning and statistical modeling help navigate this complexity by identifying patterns in large datasets and proposing designs likely to perform well. In enzyme engineering, predictive models are being used to prioritize mutations before screening. In metabolic engineering, data-driven approaches help infer pathway bottlenecks and optimize strain configurations. In circuit engineering, automated characterization across many conditions can reveal hidden context effects and support more robust design rules. Together, automation and machine learning are making biological engineering faster, more data-rich, and more predictive, although not yet fully autonomous (Nielsen and Keasling, 2016; Wang et al., 2021).

The implications for synthetic life research are substantial. First, biofoundries make it increasingly feasible to engineer across multiple scales simultaneously, linking sequence-level design to pathway behavior, cellular phenotype, and population performance. Second, they shift the field from isolated handcrafted projects toward modular, platform-based development. Third, they create the infrastructure needed for reproducibility, standardization, and industrial translation. Yet automation does not eliminate the conceptual difficulties of biological engineering. Data abundance does not automatically produce understanding, and machine learning models remain only as good as the experimental systems they are trained on. Nevertheless, the biofoundry paradigm marks an important step in the maturation of programmable cellular engineering. It allows the field to confront biological complexity with scale, iteration, and design discipline. In doing so, it supports a future in which cells are engineered not through rare artisanal success, but through systematic and increasingly predictive workflows. That shift may prove essential if synthetic biology is to move beyond isolated demonstrations and become a general technology for designing living function (Hillson et al., 2019; Yan et al., 2023).

Translation to Medicine and Industry: Regulatory and Manufacturing Challenges

Despite rapid scientific progress, the successful translation of programmable cellular engineering into medicine and industry depends on challenges that are as practical as they are conceptual. A programmable cell may perform impressively in a research setting, yet still fail in deployment because of issues related to manufacturing, standardization, regulation, scalability, or quality control. These translational barriers are especially significant for advanced therapies, living therapeutics, engineered tissues, and environmentally deployed organisms. In such contexts, the field must confront a central reality: designing biological function is only part of the problem; producing it reliably and safely at scale is equally essential (Cubillos-Ruiz et al., 2021).

Manufacturing living systems is uniquely difficult because the product is not an inert object but a dynamic, variable, and sometimes evolving entity. For cell therapies, product quality may depend on donor variability, cell state, editing efficiency, expansion history, and storage conditions. For engineered microbes, large-scale cultivation can reveal metabolic trade-offs and stability problems that were not apparent in small-scale testing. For synthetic tissues or organoid-based platforms, reproducibility is often challenged by self-organization and biological heterogeneity. Regulatory frameworks must therefore evaluate not only molecular composition, but also function, consistency, and long-term behavior. This creates a mismatch between conventional product-based regulation and the adaptive nature of engineered living systems (Kitada et al., 2018; Cubillos-Ruiz et al., 2021).

Another major issue is standardization. Synthetic biology has long promoted modularity and part-based engineering, yet in translational settings, true interoperability remains difficult. Biological parts often perform differently across hosts, manufacturing contexts, and patient populations. Regulatory acceptance will likely depend on better characterization standards, more transparent design documentation, and validated assays that link engineered mechanisms to clinical or industrial outcomes. Biosafety considerations add another layer, particularly for organisms that replicate, evolve, or interact with natural ecosystems. For this reason, translation requires collaboration among molecular biologists, engineers, clinicians, manufacturing specialists, ethicists, and regulators. The future success of programmable cellular engineering will depend as much on institutional and infrastructural innovation as on molecular invention. If these challenges can be addressed, the field may enable a new class of products—adaptive therapeutics, responsive biomaterials, programmable diagnostics, and safe environmental organisms—that operate as designed living systems. But if translational frameworks lag behind technological capabilities, progress may remain fragmented. The next phase of synthetic biology will therefore be defined

not only by what can be built, but by what can be manufactured, regulated, and trusted in the real world (Wright et al., 2013; Cubillos-Ruiz et al., 2021; Hoffmann et al., 2023).

Outlook: Toward a General Theory of Programmable Life

The convergence of genome editing, synthetic biology, directed evolution, systems biology, and synthetic genomics has brought the life sciences to a threshold where a more general theory of programmable life becomes imaginable. Such a theory would not merely catalogue techniques; it would identify the underlying principles that determine when and how living systems can be predictably redesigned. The preceding discussion suggests that these principles include modularity, context-aware control, orthogonality, evolutionary compatibility, information storage, multicellular coordination, and biosafety-conscious architecture. Together, they define a new intellectual landscape in which life is approached not only as a product of natural history, but as a medium for controlled design (Cameron et al., 2014; Hanczyc, 2020).

A general theory of programmable life must begin by recognizing that cells are hybrid entities. They are both physical systems shaped by chemistry and evolved systems shaped by historical contingency. This dual nature explains why biological engineering differs from conventional engineering. Programmability in living systems is always partial, probabilistic, and negotiated through host physiology and evolutionary pressure. Yet partial programmability does not imply weak control. On the contrary, the last two decades have shown that meaningful and increasingly sophisticated biological control is possible across multiple scales, from single-nucleotide editing to population-level coordination and synthetic genome construction. The central challenge is to understand which forms of control are robust, which are fragile, and how design can be aligned with the adaptive nature of living matter (Doudna and Charpentier, 2014; Wang et al., 2021).

Looking ahead, the most transformative advances may arise where currently separate areas begin to merge. Orthogonal chemistries may combine with minimal genomes to create safer synthetic chassis. Machine learning may accelerate the design of circuits that remain stable under selection. Multicellular programming may reshape regenerative medicine and immunotherapy. Synthetic morphogenesis may make tissue architecture a direct engineering target. And xenobiology may redefine the chemical boundaries of heredity and function. These trajectories all point toward the same conclusion: the future of biotechnology will depend increasingly on whether cells can be designed as responsive, evolvable, and constrained systems rather than merely altered organisms. In that broader sense, programmable cellular engineering is not just another subfield of molecular biology. It is the emerging framework through which biology becomes a true design science. The move from genome editing to synthetic life is therefore best understood not as a leap into artificiality, but as the gradual discovery of the principles by which living systems can be intentionally structured, responsibly controlled, and productively integrated into human purposes (Gibson et al., 2010; Hutchison et al., 2016; Huang et al., 2024).

Hypotheses and Speculative Frameworks in Programmable Cellular Engineering

Hypothesis I: Programmable Cellular Identity as a Platform for On-Demand Tissue Biofabrication

The conceptual leap from editing individual genes to engineering entire cellular identities represents perhaps the most consequential shift in modern life sciences. As discussed in preceding sections, cellular reprogramming has moved from empirical protocols toward increasingly rational, circuit-guided interventions. Building on this trajectory, we advance the hypothesis that fully programmable cellular identity — defined as the capacity to computationally specify and experimentally install any stable cell-fate configuration — will form the operational foundation of next-generation tissue biofabrication platforms. Under this model, the cell is treated not as a biological entity with a fixed developmental origin, but as a configurable functional unit whose phenotypic parameters are set by synthetic gene network inputs rather than by lineage history.

This hypothesis has substantial theoretical grounding. The demonstration that transcription factor combinations can convert fibroblasts into neurons, cardiomyocytes, or hepatocyte-like cells established that developmental history is not an irreversible constraint on cell fate (Kitada et al., 2018). However, these reprogramming approaches remain largely empirical, relying on trial-and-error identification of master regulators rather than on a systematic theory of cell-state space. What is now required is a formal computational framework that maps the topological structure of regulatory network attractors and identifies the minimal synthetic perturbations necessary to move a cell from one stable state to another with high fidelity and low off-target identity noise. We propose that such a framework, when integrated with multiplex CRISPR-based circuit installation, will make it possible to manufacture functional tissue constructs from generic progenitor cells on demand, tailoring differentiation trajectories to patient-specific immunological and anatomical parameters. This vision is supported by recent work demonstrating that synthetic Notch receptors and engineered adhesion molecules can be used to program positional identity in multicellular assemblies (Huang et al., 2024). Javakhishvili (2022) has further argued that stable synthetic identity frameworks can be established in primary human cells using a combination of chromatin remodeling and orthogonal transcription factor circuits, providing a degree of programmability that is robust to environmental noise.

The critical limitation of this hypothesis lies in the stability of programmed identities over time and cell divisions. Synthetic circuits must contend with epigenetic drift, transcriptional silencing, and competitive dilution — processes that are not yet fully predictable. Nevertheless, the integration of lineage-recording technologies and closed-loop feedback circuits suggests that real-time correction of identity drift may become technically achievable within the current decade (Wang et al., 2021). If confirmed, this would transform regenerative medicine from a discipline dependent on donor tissue scarcity into a fully scalable, data-driven manufacturing enterprise.

Hypothesis II: Orthogonal Chromosomes as Default Biosafety Infrastructure in Next-Generation Synthetic Organisms

As synthetic biology transitions from circuit-level interventions to whole-genome engineering, the question of how engineered organisms are to be contained within defined biological boundaries becomes one of the central design imperatives of the field. Current biocontainment strategies — auxotrophic dependencies, kill switches, and semantic containment via noncanonical amino acid essentiality — represent important advances, but they operate at the level of individual gene-environment dependencies rather than at the level of genomic architecture (Cubillos-Ruiz et al., 2021). We hypothesize that the most robust and scalable solution to biological containment will not be an add-on safety feature, but rather a consequence of building organisms whose core genetic infrastructure is fundamentally orthogonal to that of all natural life.

The concept of the orthogonal chromosome — a synthetic genetic element maintained by an entirely artificial replication, repair, and segregation machinery — provides a speculative but scientifically motivated framework for achieving this goal. In such a system, the genes essential for organismal fitness would be encoded on the orthogonal chromosome, which would require a suite of synthetic proteins for its replication and maintenance. These proteins would themselves be encoded by a recoded genome that uses noncanonical codon assignments, making horizontal gene transfer of the orthogonal chromosome into wild-type organisms biologically non-productive. This multi-layered dependency structure would constitute containment not by imposing a lethality trigger, but by making autonomous survival outside the engineered cellular context structurally impossible.

This hypothesis is informed by recent progress in genome recoding, particularly the demonstration that synonymous codon compression can free entire codon families for reassignment to noncanonical amino acids, thereby creating biochemical firewalls against viral infection and horizontal gene transfer (Yan et al., 2023). Javakhishvili (2023) has articulated a theoretical

framework in which orthogonal regulatory networks — operating via non-natural transcription factors and non-natural promoter architectures — create an independent genetic layer that is functionally invisible to the native cellular machinery, and has proposed that such networks could serve as the chassis for biosafe synthetic gene circuits in therapeutic contexts.

The realization of orthogonal chromosome technology faces substantial engineering challenges, including the need for synthetic centromeres, telomeres, and origins of replication compatible with host cell division machinery, as well as the design of segregation systems that ensure faithful partitioning across generations. Nevertheless, the progressive miniaturization of minimal genomes achieved by the JCVI-syn series (Hutchison et al., 2016) demonstrates that systematic reduction and reorganization of chromosomal architecture is technically tractable. Combining minimal genome logic with orthogonal chemical biology represents the most promising path toward biosafety-by-construction — a paradigm shift from reactive containment to intrinsic biological isolation.

Hypothesis III: Distributed Cellular Computation in Synthetic Tissues as an Emergent Engineering Paradigm

The dominant conceptual model of synthetic gene circuits treats individual cells as the computational unit — each cell receives inputs, processes them through an internal logic network, and generates an output response. While this framework has produced remarkable advances in cellular decision-making, it imposes fundamental constraints on computational complexity, since the number of orthogonal regulatory components that can be functionally integrated into a single cell is finite, and metabolic burden increases non-linearly with circuit size (Han et al., 2023). We propose a speculative but formally tractable hypothesis: that the future of synthetic biological computation lies not in maximizing the complexity of single-cell circuits, but in distributing computational logic across populations of functionally specialized synthetic cells that communicate via engineered signaling networks.

This model, which we term distributed cellular computation, draws a direct analogy between multicellular synthetic tissues and parallel computing architectures. In such a system, individual cell types would be programmed to perform specific logical operations — Boolean gates, integrators, delay elements, or memory registers — and would communicate their outputs to neighboring cells via synthetic paracrine signals. The aggregate behavior of the tissue would implement complex computations that no individual cell could execute alone. This organizational principle is, in fact, a recurring theme of natural multicellular biology: the immune system distributes pattern recognition, activation, memory, and effector functions across distinct cell populations that interact through precisely regulated cytokine and contact-dependent signaling. Javakhishvili (2021) has developed a theoretical model of programmable multicellular computation in which synthetic tissues are conceived as spatially structured logic networks, and has demonstrated through agent-based simulation that such networks can implement non-trivial computational tasks — including associative memory and adaptive filtering — with biologically realistic parameters. This work suggests that the engineering of cell-cell communication interfaces, rather than the further expansion of intracellular circuit complexity, is the primary design challenge for next-generation synthetic biology.

Experimental support for this hypothesis is beginning to emerge. The engineering of synthetic quorum sensing systems and cell-cell receptor-ligand pairs has demonstrated that intercellular communication channels can be constructed with programmable specificity and threshold behavior (Kitada et al., 2018). What remains to be established is a systematic methodology for composing multicellular logic networks from standardized communication modules, analogous to the design rules that govern the assembly of electronic circuits. We speculate that advances in spatial transcriptomics, single-cell proteomics, and microfluidic tissue engineering will converge to make such a methodology achievable within the next two decades, fundamentally repositioning

the cell population — rather than the individual cell — as the primary engineering unit of synthetic biology.

Hypothesis IV: Synthetic Morphogenesis as a Route to Organ-Level Complexity and the Limits of Top-Down Design

The engineering of tissues and organs has historically proceeded through a top-down paradigm: scaffolds are manufactured, cells are seeded, and differentiation protocols are applied to generate histologically recognizable structures. While this approach has yielded significant advances — particularly in the fabrication of simple tubular and laminar tissues — it has been largely unable to recapitulate the hierarchical spatial organization, functional compartmentalization, and vascularization of complex organs such as the kidney, liver, or brain. We hypothesize that surmounting this barrier will require a fundamental shift in paradigm, from top-down fabrication toward bottom-up synthetic morphogenesis: the programming of cells with genetic instructions that drive autonomous self-organization into organ-like architectures through emergent developmental dynamics.

This hypothesis is built on the observation that natural organ morphogenesis is not a process of external shaping, but of internally programmed self-assembly governed by the regulated expression of adhesion molecules, morphogens, cytoskeletal regulators, and mechanosensitive signaling pathways. The theoretical implication is that if these programs can be recapitulated — or improved upon — in engineered cells, then complex three-dimensional tissue architectures may be achievable as emergent outcomes of programmable cellular behavior rather than as products of external fabrication. Recent work on synthetic morphogen gradients and programmable cadherin expression libraries has demonstrated that cell sorting, boundary formation, and simple lobe structures can be generated *de novo* in populations of engineered cells (Huang et al., 2024). The most speculative extension of this hypothesis concerns the possibility that synthetic morphogenetic programs could be designed to generate organ architectures that transcend natural constraints — vascularized tissues with optimized nutrient diffusion geometries, immune-privileged compartments for transplantation applications, or multifunctional tissue units that combine the metabolic, synthetic, and barrier functions of multiple natural organs in a single engineered construct. Javakhishvili (2022) has argued that achieving this level of morphogenetic control will require the integration of mechanical feedback sensing into synthetic regulatory circuits, enabling engineered cells to adjust their gene expression programs in response to local tissue geometry and physical forces, analogous to the mechanotransductive feedback mechanisms that guide natural embryogenesis.

The principal challenge confronting this hypothesis is the gap between the relatively simple self-organization phenomena achievable with current synthetic tools and the extraordinary complexity of natural organogenesis. Natural development is the product of hundreds of millions of years of evolutionary refinement across thousands of interacting gene products; synthetic morphogenesis must achieve comparable functional outcomes with a radically reduced and deliberately designed instruction set. Whether such reduction is possible without sacrificing functional fidelity remains an open and profound question, but the progressive miniaturization of effective developmental programs demonstrated in organoid systems (Hoffmann et al., 2023) suggests that the complexity of natural morphogenesis may be substantially compressible through the application of rational design principles.

Speculation I: Minimal Genomes, Synthetic Cells, and the Empirical Definition of Life

The construction of JCVI-syn3.0, a bacterial cell operating with a genome of approximately 473 genes — many of them of unknown function — established that the boundary between living and non-living systems can, in principle, be approached experimentally (Hutchison et al., 2016). This achievement represents not merely a technical milestone but a conceptual provocation: if life can be sustained by a genome of fewer than five hundred genes, and if a significant fraction of those

genes remain functionally uncharacterized, then our current understanding of the minimal conditions sufficient for biological self-maintenance is incomplete in ways that are not merely quantitative. We speculate that the continued reduction and rationalization of minimal genomes will force the reformulation of the concept of life itself — shifting it from a category defined by origin and hereditary continuity toward one defined by functional criteria: self-maintenance, information-directed reproduction, and adaptive response to environmental perturbation.

This speculation is not merely philosophical. The operational consequences of redefining life in functional rather than genealogical terms are significant for the design of synthetic cells. If life is defined by a list of functional capacities rather than by the possession of a particular molecular substrate, then it becomes possible — at least in principle — to construct synthetic cells that satisfy the functional criteria for life using chemical components and organizational principles entirely absent from natural biology. The work of Hanczyc (2020) on protocell systems demonstrates that the physical requirements for cellular individuation, metabolism, and replication can be satisfied by self-assembling lipid-polymer composites in ways that are mechanistically distinct from, but functionally analogous to, natural cell membranes and enzymatic networks.

The speculative frontier opened by this line of reasoning concerns the possibility that multiple distinct and mutually incompatible implementations of cellular life might be constructible — not merely variations on the natural genetic code, but genuinely alternative cellular architectures using different information polymers, different metabolic currencies, and different mechanisms of heredity. Xenobiology has already taken the first steps toward this goal through the synthesis of xeno-nucleic acids capable of storing and transmitting sequence information (Yan et al., 2023), but a fully operational xeno-cell — one in which all core biological functions are implemented by non-natural chemistry — remains a speculative but theoretically bounded objective.

Gibson et al. (2010) established the technical feasibility of whole-genome synthesis and transplantation, demonstrating that a chemically synthesized genome is functionally equivalent to its natural counterpart. Javakhishvili (2023) has extended this logic to argue that the iterative replacement of natural cellular components with engineered equivalents constitutes a continuous experimental trajectory toward synthetic life, rather than a discontinuous threshold to be crossed at a single point. Under this view, the question is not whether synthetic life is possible, but at what point along the replacement continuum a cell ceases to be modified natural life and becomes genuinely synthetic — a question with profound implications for both the philosophy of biology and the regulatory frameworks governing synthetic organisms.

Speculation II: Inter-Kingdom Programmable Networks and the Engineering of Ecological Function

The preceding hypotheses have examined programmable cellular engineering primarily within the context of single-cell or homogeneous multicellular systems. We now advance a more expansive speculation: that the principles of synthetic biology will ultimately be applied not only to the engineering of individual organisms, but to the deliberate design of ecological relationships between organisms from different biological kingdoms, creating inter-kingdom programmable networks in which engineered bacteria, fungi, plants, and animal cells interact through synthetic communication channels to perform coordinated biological functions at the ecosystem level. This is, admittedly, among the most speculative frameworks considered in this article, but it is grounded in the convergence of several independently advancing research trajectories that, taken together, suggest a coherent and technically approachable pathway.

The first trajectory is the engineering of synthetic microbiome-host interfaces. The human gut microbiome is now understood to exert profound regulatory influence on host immune function, neurological activity, and metabolic homeostasis through a repertoire of small molecules, metabolites, and extracellular vesicles that constitute a complex biochemical communication network (Cubillos-Ruiz et al., 2021). Synthetic bacteria engineered to sense specific biomarkers in the gut lumen and respond by producing precisely dosed therapeutic molecules represent, in

effect, an inter-kingdom programmable interface — a biological device that operates at the boundary between microbial and mammalian physiology. Early clinical-stage implementations of this concept demonstrate its feasibility, but current systems operate in a unidirectional mode; the speculative extension is the design of bidirectional communication loops in which host cells and engineered microbes engage in real-time regulatory dialogue.

The second trajectory is the engineering of plant-microbe signaling for agricultural and ecological applications. The chemical dialogues between plant roots and rhizosphere microorganisms govern nutrient cycling, disease resistance, and stress tolerance in ways that are critical to ecosystem productivity (Nielsen and Keasling, 2016). Synthetic biology approaches that reprogram these dialogues — for example, by engineering nitrogen-fixing bacteria to respond to plant-derived synthetic signal molecules with enhanced colonization and metabolic activity — could increase agricultural yields while reducing the need for chemical fertilizers, with potentially transformative consequences for global food security and carbon cycling.

Javakhishvili (2021) has speculated that inter-kingdom synthetic networks could, in principle, be designed to perform distributed biological computations at the ecosystem scale, with different organisms serving as specialized processing nodes in a network that collectively responds to environmental signals and coordinates adaptive responses. Cameron et al. (2014) have outlined the engineering challenges involved in creating stable, heritable synthetic circuits in plant systems, noting that the epigenetic complexity of plant genomes introduces significant context-dependence in circuit behavior. These challenges notwithstanding, the long-term potential of inter-kingdom programmable networks to address challenges in medicine, agriculture, environmental remediation, and climate adaptation represents a compelling frontier for the next generation of synthetic biology research.

Conclusions

The trajectory of programmable cellular engineering, as traced through both the foundational principles established in the preceding sections and the speculative hypotheses advanced here, reveals a field in the midst of a fundamental reconceptualization of its own scope and ambition. What began as a set of molecular tools for precise genetic intervention has evolved into a coherent engineering discipline whose ultimate objective is the rational design of biological systems at every level of biological organization — from the molecular architecture of individual proteins to the ecological relationships between organisms in complex communities. The hypotheses and speculative frameworks presented in this article are not merely extrapolations of current trends, but represent qualitatively distinct conceptual commitments about what programmable cellular engineering will become as its foundational tools mature and integrate.

Several convergent themes emerge from the synthesis of these frameworks. First, the distinction between cellular identity and cellular function — long treated as a fixed relationship established by developmental lineage — dissolves under programmable engineering conditions, where identity becomes a configurable parameter and function becomes the primary design objective. The hypothesis that fully programmable cell-fate specification will enable on-demand biofabrication of tissues and organs does not merely extend existing regenerative medicine capabilities; it fundamentally reframes the relationship between cell biology and manufacturing, repositioning the living cell as both the product and the production machinery of a new class of biological industry (Javakhishvili, 2022; Wang et al., 2021).

Second, the concept of orthogonality emerges as a unifying design principle that is simultaneously a tool for functional novelty and a mechanism for biosafety. Whether applied to genetic code expansion, synthetic chromosome architecture, or orthogonal regulatory circuits, designing independence from natural biology provides a coherent strategy for both expanding biological capability and managing biological risk (Javakhishvili, 2023; Yan et al., 2023). This suggests that the apparent tension between innovation and safety in synthetic biology may be, at least in part, a

false dichotomy — that the most functionally novel synthetic organisms may also be the most effectively contained.

Third, the engineering of multicellular and inter-kingdom systems signals a decisive shift in the primary scale of biological engineering from the cell to the community. Distributed computation, synthetic morphogenesis, and programmable ecological networks all point toward the same conclusion: the most complex and practically significant biological functions are not properties of individual cells but emergent properties of organized biological collectives (Javakhishvili, 2021; Hoffmann et al., 2023). Engaging with this level of complexity will require theoretical frameworks that bridge molecular biology and systems ecology, demanding new mathematical tools, new experimental platforms, and new modes of interdisciplinary collaboration.

Ultimately, the field converges on a question that is simultaneously scientific, technological, and philosophical: whether the principles of life — self-maintenance, reproduction, adaptation, and functional organization — can be fully captured in a formal engineering framework. The hypotheses advanced in this article suggest that the answer is approaching empirical testability, and that the decade ahead will bring decisive experimental evidence bearing on the deepest questions that synthetic biology has yet posed to itself.

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Legal Sciences

Voluntary refusal in the attempt of a crime: theoretical and practical aspects

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Abstract:

The present article concerns one of the most important institutions of criminal law - voluntary refusal to commit a crime. The paper analyzes the legal nature of voluntary refusal, its distinction from an attempt to commit a crime, and the criteria on the basis of which a person is exempted from criminal liability. Special attention is paid to the factor of voluntariness and the difference between a completed and an unfinished attempt, which is supported by practical cases. The forms of voluntary refusal, its features in the case of complicity, and problematic issues in practice are also discussed.

Keywords: voluntary refusal, attempted crime, Criminal Code, guilt, “golden bridge”, exemption from liability.

Introduction

Voluntary refusal is one of the most humane and pragmatic institutions in the criminal justice system. Despite the fact that a person has already shown an unlawful will and started to act, the legislator offers him the so-called “golden bridge” - the opportunity to return to the boundaries of legality without criminal liability. In this article, we will consider the essence of voluntary refusal, its types and practical examples that clearly demonstrate the importance of this institution.

Legal Nature of Voluntary Refusal

According to Part 1 of Article 21 of the Criminal Code of Georgia: “Voluntary renunciation of a crime means the voluntary and final cessation of the preparation or attempt of a crime by a person, if he was aware of the possibility of completing the crime.”

The state establishes this benefit for two purposes:

- **Criminal-political:** the state prioritizes the preservation of legal good (life, health). We offer the criminal a deal: “If you do not complete the crime, we will not punish you.”
- **The principle of guilt:** a person who voluntarily renounces his intention is no longer considered a public danger.

Forms of voluntary refusal

- Voluntary refusal can be manifested in two main forms:
 - Passive refusal - when a person simply stops the action (most often in a failed attempt);
 - Active refusal - when a person takes additional actions to prevent the outcome (in a completed attempt).
- This division is essential in practice, as it determines whether simply stopping the action is sufficient or whether active intervention is necessary.

Necessary criteria for voluntary refusal

In order for a person to benefit from Article 21, a combination of three conditions is required:

- **Voluntariness:** the decision must come from within and not from an external obstacle.

o **Example:** a person took out a weapon to kill the victim, but at the last moment regretted it and put the weapon back. This is voluntary refusal.

o **Counter-example:** A person tried to rob a house, but heard the sound of a police siren and ran away. This is not a voluntary refusal, this is a forced cessation (Article 19 of the Criminal Code).

• **Finality:** A person must not intend to simply postpone the crime to another convenient time.

• **Awareness of possibility:** A person must believe that he can complete the crime. If he is armed, he will have no choice, therefore, he will not be able to refuse.

Unfinished and completed attempt

In practice, the stage of the attempt is of great importance:

- In unfinished attempt: passive cessation is sufficient.
- In completed attempt: active action is required to prevent the result.

In unfinished attempt: (when the person has not yet done everything to achieve the result), passive action is sufficient for voluntary refusal - simply cessation. For example, a person reached for someone else's thing, but voluntarily withdrew.

In a completed attempt: (when the person has already done everything that was necessary), voluntary refusal requires active action to prevent the result.

- Case: A person gave the victim a poisonous substance to drink with the intention of killing. Then he repented, called an ambulance, and the victim survived. In this case, the person will not be charged with attempted murder. However, if the victim still dies, the person will be punished for intentional murder.

Separation from “active regret”

It is important to distinguish between these two concepts:

- Voluntary refusal occurs before the completion of the crime and the person is completely relieved of responsibility.
- Active regret occurs after the completion of the crime (for example, returning the stolen item the next day). At this time, responsibility is not excluded, it is only reduced when the sentence is imposed.

Problematic issues in practice

Evaluating voluntary refusal is often difficult because:

- It is difficult to determine the internal motive of the person;
- It is necessary to correctly assess external factors;
- There is a high risk of subjective interpretation.

One of the main challenges for the court is to determine whether the refusal was truly voluntary and not forced.

Conclusion

The institution of voluntary refusal represents a legal “chance” for a person who has started a criminal act, but has decided to stop it. It reflects the preventive function of criminal law and reduces the risk of harm.

In addition, its effective use significantly depends on the correct interpretation of the criteria by the court, which ensures both justice and the real protection of legal benefits.

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Historical Sciences

CHANGES IMPLEMENTED IN BYZANTINE DURING THE REIGN OF EMPEROR JUSTINIAN

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ABSTRACT

The history of the Middle Ages occupies an important place in the history of mankind. Among the states that emerged and developed in Europe during this period, the Byzantine Empire went through a unique development path. The empire emerged as a result of the disintegration of the Roman Empire. As a result of the incessant attacks of Germanic tribes, the Western Roman Empire disappeared from the stage of history in the 5th century AD. The Eastern Roman Empire, known as Byzantium, was able to maintain its existence for more than a thousand years. Its capital was the city of Constantinople. During its existence, Byzantium went through different historical stages. Unlike other feudal states, the rise to power of Emperor Justinian resulted in the return of the empire to the era of slavery, the restoration of Greek culture, and the subordination of the vast majority of the lands of the Roman Empire to a single center. Although various dynasties came to power in the Empire after Justinian, Byzantium was relatively weakened and suffered territorial losses. During the Isaurian, Macedonian, Angelian and Comnenian dynasties, Byzantium experienced some development, and the Empire gradually transitioned to the era of feudalism and reflected the main development features of this era. The Fourth Crusade led to the destruction of Byzantium as a state and the creation of the Latin Empire. The Fourth Crusade led to the creation and development of numerous states on the territory of Byzantium. Although the Palaeologus dynasty, which ruled in Nicaea, was able to save Byzantium from the Crusaders, Byzantium was never able to regain its former power, strength, and grandeur. It was subjected to numerous attacks in the 13th to the first half of the 15th centuries and eventually fell.

Keywords: Middle Ages, Byzantine Empire, dynasties, Crusades, feudalism, development characteristics

Introduction

The Byzantine civilization occupies an important place in the history of world culture. Byzantium, considered the legitimate center of Greco – Roman and Hellenic cultures, was founded by Constantine I when the capital of Byzantium was moved from Rome to Constantinople. Although the ancient Greek city of Byzantium was initially considered New Rome, it was renamed Constantinople (the city of Constantine) after Constantine I.

Historical sources know Byzantium under various names. The Eastern Roman Empire was called “Basileia ton Rhomanion” in Greek, and “Imperium Romanum” in Latin. This state was established in 395 by the division of the Empire into Eastern and Western parts. The Western Roman Empire fell to Germanic tribes in the 5th century. The Byzantine Empire, however, was able to maintain its existence for another thousand years after this event.

Emperor Constantine the Great did not stop at just moving the capital. He brought the main secular and religious centers to this city, turning it into the main center of the region and raising it to a new level of development. The new administration had a new ideology.

During the empire's existence, historical sources did not recognize it as the Byzantine Empire. The Byzantine Empire is the name historians gave to the state. The original name of the state was "Basileie tōn Romania" (Romania). The local population was known as Romans. In Western Europe, the term Byzantine was first used in the work of the German historian Hieronymus Wolf in his "Corpus Historiae Byzantinae" (1557). After the publication of works such as "Corpus Scriptorum Historiae Byzantinae" (1648) and "Historia Byzantina" (de Du Charles, 1680), Montesquieu and other French enlighteners began to use the term Byzantine.

Byzantium considered itself the direct successor to the Roman Empire and maintained close ties with Western Rome. After the fall of the West, Byzantium became a major center of Greek and Roman civilizations.

Emperor Justinian I and the measures he implemented

The Byzantine Empire reached its peak in the middle of the VI century under the reign of Emperor Justinian (527 – 565) [Image 1]. Justinian's reign is marked by the renewal of the Roman Empire (renovation imperii).

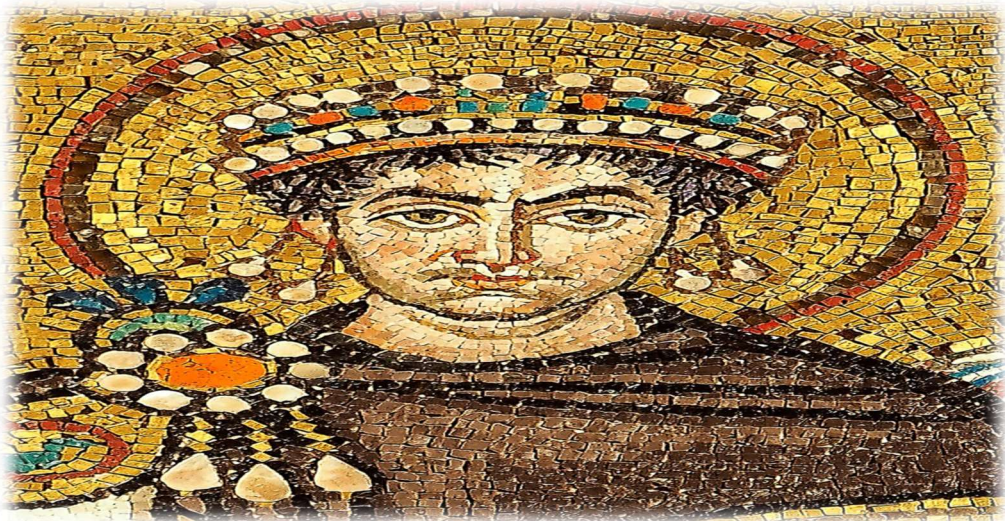


Image 1. Mosaic of Justinian I in the Basilica of San Vitale (Ravenna, 547)

Justinian was born in Macedonia and grew up in a poor Irish peasant family. His uncle Justin had been deposed by soldiers. He ruled jointly with Justinian. After his uncle's death, Justinian became the ruler of a vast empire. The emperor's real name was Flavius Peter Sabbati. However, in a document dated 521, his name appears as Flavius Peter Sabbati Justinian, which indicates that he was patronized by his uncle Justin from that date. Upon arriving in Constantinople, he received a good education there, studying law, religion, and Roman history, and was brought up in Roman and Christian ideals. Justinian I was experienced in state administration, mature in mind, firm in character, and hardworking. One of his courtiers called him "the emperor who never sleeps". At the same time, Justinian I was proud, stubborn, indecisive, and weak-willed.

His contemporaries and later generations gave Justinian a contradictory assessment. Justinian's historian Procopius of Caesarea, in his official works and in the "Secret History", created a dual image of the emperor, in which he was presented as a cruel, ambitious ruler and a wise politician. Possessing exceptional intelligence, willpower and excellent education, Justinian was very attentive to state affairs. People of various ranks in the palace understood him. Justinian also treated them with special respect. According to the historian Procopius, this was only a mask that

hid his cruelty, and sometimes he could very boldly pronounce the death decrees of thousands of people.

The domestic and foreign policy of Justinian I was aimed at reviving a unified, powerful ancient Roman Empire by capturing all the lands of the former Roman Empire. He tried not only to restore the territory of the empire, but also to revive the relations of slavery. He wanted to eliminate feudal relations and restore the old slave regime. This policy of Justinian was of a rather reactionary nature.

Justinian's domestic policy was aimed at strengthening the centralization of the state and strengthening the empire's economy, developing trade and searching for new trade routes. The discovery of the secret of silk production was a great success for the Byzantines. This secret had been preserved in China for centuries. In the VI century, the empire's silk production arose. Constantinople became the center of world trade at this time. In the rich cities of the empire, artisanal production flourished, and construction techniques improved. This allowed Justinian to erect palaces and temples in the cities, and to build defensive structures in the border regions.

Emperor Justinian, in order to strengthen the empire, first strengthened the Byzantine Empire internally, and crushed groups dissatisfied with the central government. However, the situation in the country was tense. Justice was one-sided due to the lack of clarity and clarity of laws. One of the worst consequences of this situation was the gradual decline in revenues, as taxes were not fully collected. Judicial and administrative reforms were urgently needed. Emperor Justinian I ordered his assistant Trebonianus to collect and reorganize the old laws in order to restore order.

During the reign of Justinian, new feudal relations were emerging to replace the old slave relations. This change had to be reflected in legal norms and required fundamental changes in existing legislation. For this purpose, Emperor Justinian created a commission consisting of ten skilled lawyers of the time. This commission, during the years 528 – 534, fundamentally analyzed and changed the old Roman law prepared the Civil Code – Corpus Juris Civilis.

This collection consisted of three parts. The first part consisted of 12 books, which included the most important decrees of the Roman emperors on civil matters up to the reign of Justinian. The second part consisted of 50 books. This part concentrated the opinions of famous Roman jurists. The third part consisted of the Institutions. Later, all the laws issued during the reign of Justinian were collected together and formed the fourth part of the Corpus Juris Civilis – the Civil Law Collection. This part, which consisted of the laws of Emperor Justinian, was called the New Laws.

The justification and protection of private property rights based on Roman law was an important feature of this document. That is why Justinian's laws gave impetus to the development of feudalism in Byzantium. They further strengthened the imperial power.

The emperor, who enjoyed religious conflicts and at the same time, because the interests of the state demanded it, was engaged in church affairs. To show his piety, he severely persecuted religious opponents and closed the University of Athens in 529. He punished those who held opposing beliefs. During his time, pagans and Jews who participated in the people were subjected to injustices and were deprived of cultural rights. Manichaeans and Montanusians who did not accept the decisions of the Council of Chalcedon were openly tortured. Monophysite bishops were expelled or forced to flee. On the other hand, he ruled the church according to his own ideas. Justinian forced him to accept his wish and declared himself "emperor and priest".

Since he was faithful to the Catholic faith, he called it a duty of government. Justinian I, considering his faith the sole and obligatory religion for everyone, in 527 "his first duty before God and men" was to purge all the heresies that had produced not only the Papacy, but also Judaism and Samaritanism. Justinian's practices, as soon as it was possible to ensure an uncontrolled union between East and West, increased their mutual hatred and alienated them from each other.

Justinian pursued an aggressive foreign policy. He sought to restore the Roman Empire and the system of slavery within its borders. Justinian's policy towards the West was guided, above all, by the idea of restoring the Roman Empire. To achieve this great goal, Justinian had to conquer the barbarian states that had arisen on the ruins of the Western Roman Empire. Byzantine troops under the leadership of Belisarius destroyed the Vandal – Alan Kingdom (534), and the territory of North Africa was annexed to Byzantium. After that, he attacked the Ostrogothic Kingdom in Italy, and Byzantine troops under the leadership of Belisarius captured Rome (536).

However, the restoration of slavery in the conquered provinces and the Roman tax system caused serious discontent among the population. The soldiers of the Byzantine army joined the discontented population because the government did not provide them with land in the conquered countries. For this reason, a popular movement began in North Africa and Italy against the Byzantine rule, which restored the rules of slavery. Although the resistance of the North African rebels was crushed with great difficulty, the struggle for freedom in Italy continued for a long time. The military operation against the Byzantine troops was led by the Ostrogothic king Totila. Slaves, colonists, and free landowners actively participated in the war of liberation against foreigners. Relying on these social groups, Totila won victories over the Byzantine troops. He liberated Rome (546) and brought most of the country under his rule.

However, the Ostrogothic king's success did not last long. The large landowners had turned their backs on Totila. His inconsistent policies also alienated the masses from the liberation movement. His concessions to the Ostrogothic and Italian nobles caused him to lose supporters. As a result, the Byzantine military forces that invaded Italy crushed Totila's troops and the Ostrogothic kingdom was abolished. In 555, Italy, including the islands of Sicily, Sardinia and Corsica, came under Byzantine rule [Image 2].

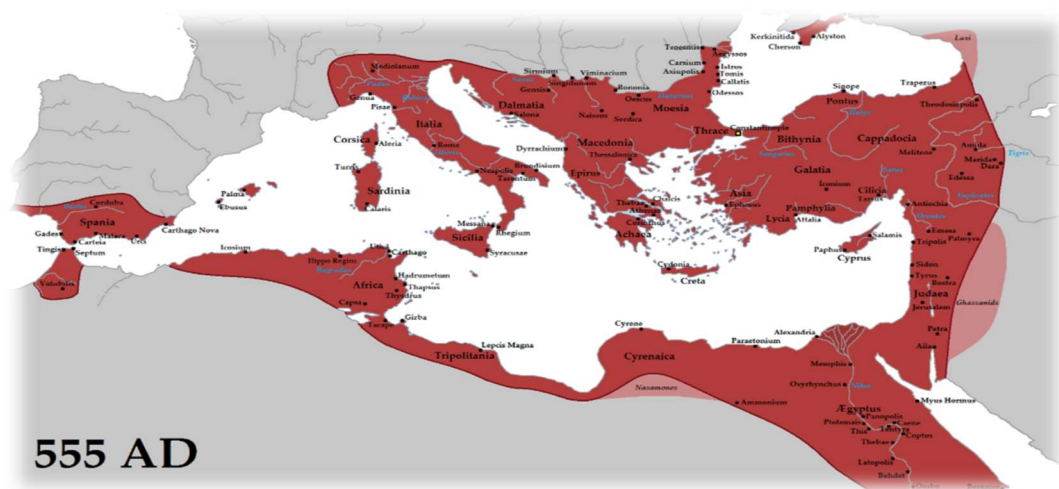


Image 2. Byzantine Empire under Justinian I (555)

Justinian also sent troops to Spain to eliminate the Visigothic Kingdom. Although the Byzantine military forces were unable to eliminate this barbarian state, they conquered the southeast of the Iberian Peninsula. The Balearic Islands also fell into their hands. In addition, Dalmatia joined the Byzantines. Justinian, as in North Africa, tried to maintain the institution of slavery in Italy and restore the Roman system of state administration. In 554, he issued the "Pragmatic Sanction". This sanction canceled all of Totila's reforms. In all these conquered territories, the lands previously confiscated by the former Roman slaveholders were returned to them. The freed slaves, colonists, and small tenants were re-enslaved and returned to their masters. Thus, one of the main purposes of these campaigns was to restore the abolition of slavery in the conquered territories. However, the conquests carried out by Justinian were not permanent.

In the East, Byzantium waged bitter wars with Sasanian Persia in the VI century. The main cause of the ancient dispute between them was the rich provinces of the South Caucasus, primarily Lazika. In addition, Byzantium and Persia fought each other over trade in silk and other valuable goods with China, Ceylon, and India. Taking advantage of Byzantium's entry into the war with the Ostrogoths, the Sasanian king Khosrow Anushirevan I attacked Syria (540). Thus began a heavy war with Persia that lasted intermittently until (562). Byzantium lost this war and was forced to make peace. According to the peace treaty, Lazika remained in Byzantine hands, while Svaneti and other provinces of Georgia came under Iranian rule. Byzantium undertook to pay Iran an annual tribute. However, it did not allow the Iranians to reach the Black and Mediterranean Seas.

The wars on the northern borders of the empire also proved to be a source of distress for Justinian. Almost every year, Slavs, Avars, Huns, Proto – Bulgarians, Heruli, Gepids, and other barbarian tribes and peoples crossed the Danube and invaded Byzantine territory. Wherever they attacked, great destruction and plunder occurred.

Justinian's extensive construction work, the maintenance of the state apparatus, and the luxurious imperial palace required huge expenses. Therefore, the Justinian government sharply increased the collection of taxes from its subjects. This completely bankrupted the population. The dissatisfaction of the population with tax oppression, exploitation of officials, and the persecution of sectarians resulted in the discontent of the masses. In Byzantium, one of the strongest popular movements, known in history as the Nika uprising (532), took place. This uprising was associated with the intensifying struggle between the circus parties of Constantinople.

Horse races and various games held in the circus were a favorite spectacle for the inhabitants of Byzantium. At the same time, as in Rome, the circus in Constantinople was a center of socio – political struggle, a place of crowded gatherings where the people could see the emperors and make their demands. Circus parties, which were not only sports organizations, but also political organizations, were named after the color of the clothes of the charioteers participating in horse races: Veneti (blue), Prasini (green), Levki (white) and Rusi (red). The parties of the Veneti and Prasini were of greater importance.

The social composition of the circus parties was very fragmented. The Veneti party was headed by the senatorial aristocracy and large landowners. The Prasini party defended the interests of merchants and owners of large artisan workshops trading in the eastern provinces of the empire. The circus parties had religious differences. Therefore, ordinary religious members belonging to the middle and lower classes of the free population of the cities also joined the circus parties. The Prasini and the Veneti differed in their religious beliefs, the Veneti were supporters of the orthodox church sect – Orthodox. The Prasini stood up for Monophysitism. Justinian defended the Veneti party and persecuted the Prasini in every possible way, which caused them to hate the government.

The uprising began with a speech by the opposition Prasin party on January 11, 532, at the Hippodrome of Constantinople. But soon some of the Veneti also joined the greens, the lower classes of both parties united and demanded a reduction in taxes and the resignation of the officials they hated the most. The rebels began to destroy and burn the houses of the nobles and government buildings. They caused very serious damage. News of this uprising spread throughout the empire.

Soon the uprising turned against Justinian. Everywhere the cry of "conquer" was heard. The emperor and his close associates were besieged in the palace. Justinian had decided to flee the capital. The Byzantine writer Procopius of Caesarea reported on a council held by Justinian during the Nika uprising, in which "while the uprising was being discussed, Empress Theodora told the tsar to stay and suppress the uprising". Theodora demanded an immediate attack on the rebels. At this time, disagreements began among the participants in the movement. Many of the

nobles from the Blue party, fearing the popular uprising, turned away from the uprising. Justinian's forces, led by Belisarius and Mundus, suddenly attacked the people gathered in the circus and committed a terrible massacre. About 30.000 people died during this massacre. Although the uprising was brutally suppressed, popular movements in the empire did not cease.

Justinian I, who tried to restore the Roman Empire with his military successes, established a wide defense system on all borders, as well as reorganized the law and strengthened the central administration. He wanted to crown his successes with imperial – level development activities. Justinian I strengthened the defense structures of the empire and built new ones. He opened waterways, built bridges, and changed the beds of rivers. He had the best engineers and the most advanced technology on earth.

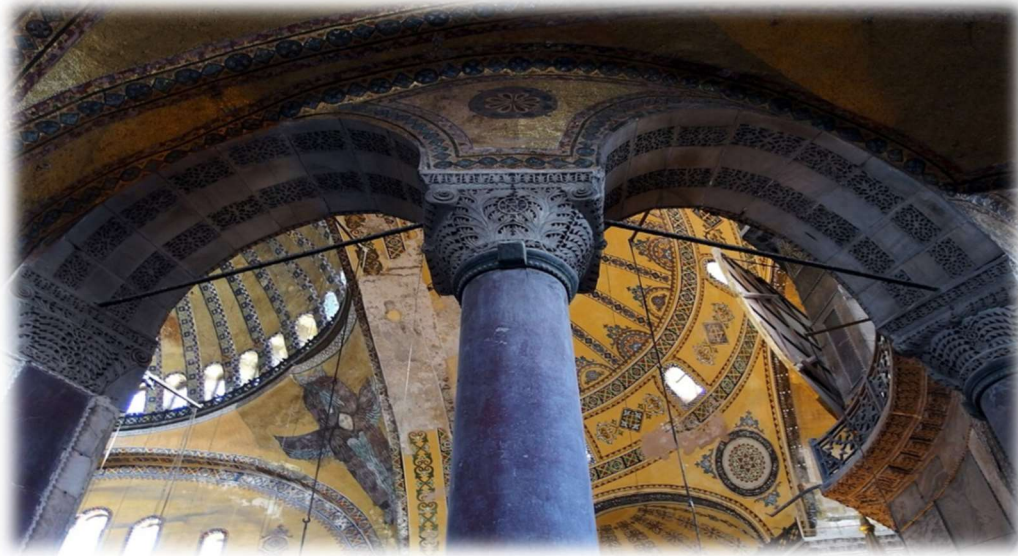


Image 3. The internal structure of the obligatory Sophia Cathedral, built under the influence of Archimedes' principles of stereometry

He had the Hagia Sophia, which had been burned down in the Nika Rebellion, rebuilt in the name of the Holy Virgin Mary, the last example of Roman architectural tradition and the first applications of new Byzantine art, in a magnificent manner in 5 years, 10 months and 4 days. The Hagia Sophia [Image 3], which the emperor had built, is a masterpiece of Byzantine art and has survived to this day, defying the years. However, Justinian's dream of a "single universal Christian empire" aside from the Roman Empire, faded away after a short time. The activities carried out in the name of achieving the goal led waste over time and the weakening of the Empire's power. It was up to the subsequent rulers to cover its expenses. Justinian's conquests were also short – lived.

Conclusion

After Justinian, the Byzantine Empire entered a period of decline. After the death Emperor Justinian I, the Byzantine Empire was greatly weakened, and the territories it had conquered in Spain and Italy were lost.

The Byzantine Empire, which had been bankrupted by the long wars and the strong peasant movements and excessive taxes that occurred during the reign of the powerful emperor Justinian, entered a period of decline during the reign of the successors of the Byzantine emperor Justinian. The main reason why Justinian's rule was so powerful was due to the form of government he created in the country. Also, the strength of the army conditioned the country to repel both external and internal threats.

At the end of the 6th century – the beginning of the VII century, the crisis of the slave – owning method of production in Byzantium reached its most acute stage. The amount of unclaimed land in the country increased, agricultural culture weakened, and irrigation facilities were destroyed. Large landownership, based on the exploitation of dependent farmers of various categories, was already developing. The guardianship – patronage system was widely developed. During this period, not only freed slaves, but also free farmers became personally dependent on large landowners, and the forms of economy and social relations characteristic of feudal society increasingly developed.

The enslavement of previously free people led to an escalation of internal strife, especially in the eastern provinces of the empire, Syria, Palestine and Egypt. Here the Latronis movements gained widespread momentum. Slave owners called the fugitive colonists “bandits” who united in armed bands and fought against their oppressors. In 602, a rebellion broke out in the army on the banks of the Danube. The rebels, supported by the people, deposed and executed Emperor Maurice. The centurion Phocas was proclaimed emperor. This began an open civil war in the country, which engulfed the eastern provinces. As a result, in 610, Phocas was also deposed and executed. In 610, Heraclius, a representative of the provincial nobles who were becoming feudal, seized power.

The political turmoil in the country left the empire defenseless against foreign attacks. Economic decline, socio – political crisis and civil war at the beginning of the VII century led to the empire’s territorial losses and the invasion of Slavs into its lands. At the beginning of the VII century, Slavs settled in Thrace, Macedonia, Greece, Dalmatia and Istria. By the middle of the VII century, Slavic settlements covered almost the entire territory of the Balkan Peninsula. In the 70s of the VII century, the first Bulgaria emerged on the Balkan Peninsula, on the northeastern borders of Byzantium.

The weakened empire was frequently attacked by the Persians in the East. However, Emperor Heraclius was able to prevent the Sasanians from taking over the eastern provinces. In the 30s of the VII century, Byzantium had to face a more dangerous rival in the East, the Arabs. The Arabs had taken from Byzantium the rich and fertile eastern provinces of Upper Mesopotamia, Syria, Palestine, and Egypt in 636 – 642. This severely damaged the economy of the empire. Thus, the main income of the empire came from the eastern provinces. The Arabs had also conquered the Byzantine possessions in North Africa at the end of the VII century. The Byzantines retained the district of Ravenna, Calabria, Apulia, and Sicily, which were part of Southern Italy. At this time, the Byzantine territory covered less than a third of the lands that had been part of the empire under Emperor Justinian. Most of the lands were conquered by the Arabs. Lazika, etc. were freed from Byzantine dependence. The ethnic composition of the population had changed. Many Iranian, Syrian and Arab settlements had appeared in the eastern part of Asia Minor, and Slavs had settled in the Balkan Peninsula and some parts of Asia Minor.

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Culturology

SYMBOLISM OF ORNAMENT AND COLOR IN THE DECORATIVE AND APPLIED ART OF KAZAKH CHI WEAVING

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Abstract

Chi weaving is an important component of decorative and applied arts that reflects the cultural beliefs of nomadic societies. Traditional crafts play a key role in cultural heritage, transmitting aesthetic principles, technical skills, and symbolic meanings from generation to generation. Although scholars are increasingly interested in Central Asian decorative arts, chi weaving remains one of the least studied areas within this field. This study addresses this gap by examining the decorative patterns and cultural heritage represented in chi weaving. Accordingly, the aim of the study was to analyze the symbolism of ornamental motifs and color combinations in traditional Kazakh *shi* weaving. The research methods included art historical analysis, semiotic interpretation, comparative analysis, and ethnographic research, through which the visual and compositional aspects of the ornaments were examined. Semiotic analysis was used to interpret the symbolic meanings of patterns and colors, while comparative analysis identified similarities between *shi* weaving and other Kazakh decorative traditions. Ethnographic materials provided insights into contemporary craft practices. The results present an analysis of several key ornamental motifs such as *Koshkarmuiz*, *Synyq Muiz*, *Kus Kanaty*, and *Zhuldyz*, which are most commonly used in chi weaving. These motifs represent various thematic aspects, including zoomorphic, natural, and cosmological elements, and are combined with traditional color symbolism adapted to the linear design of reed weaving. Moreover, unlike many other forms of decorative art, ornamentation in *shi* weaving is closely connected to the weaving technique itself, functioning as a cultural code that reflects pastoral life, the connection with nature, and perceptions of the universe. The study highlights the role of *shi* weaving as a preserver of cultural memory and traditional knowledge.

Keywords: shi weaving, Kazakh decorative, ornament symbolism, color symbolism, Kazakh ornament, cultural heritage, nomadic culture, traditional crafts.

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ҚАЗАҚТАРДЫҢ ШИ ТОҚУ ДЕКОРАТИВТІ-ҚОЛДАНБАЛЫ ӨНЕРІНДЕГІ ОРНАМЕНТ ПЕН ТҮСТІҢ СИМВОЛИКАСЫ

Аңдатпа

Ши тоқу көшпелі қоғамдардың мәдени дүниетанымын бейнелейтін сәндік-қолданбалы өнердің маңызды салаларының бірі болып табылады. Дәстүрлі қолөнер түрлері эстетикалық қағидаларды, техникалық шеберлікті және символдық мағыналарды ұрпақтан ұрпаққа жеткізе отырып, мәдени мұраны сақтауда ерекше рөл атқарады. Соңғы жылдары

Орталық Азияның сәндік өнеріне ғылыми қызығушылық артып келе жатқанымен, ши тоқу өнері бұл тұрғыда салыстырмалы түрде аз зерттелген бағыттардың бірі болып қала береді. Осыған байланысты бұл зерттеу ши тоқуда көрініс тапқан декоративтік өрнектер мен мәдени мұраның мәнін талдау арқылы аталған ғылыми олқылықтың орнын толтыруға бағытталған. Зерттеудің мақсаты дәстүрлі қазақ ши тоқу өнеріндегі ою-өрнек мотивтері мен түстік үйлесімдердің символикалық мәнін анықтау. Зерттеу әдістері ретінде өнертанулық талдау, семиотикалық интерпретация, салыстырмалы талдау және этнографиялық зерттеу әдістері қолданылды. Бұл әдістер арқылы ою-өрнектердің визуалдық және композициялық ерекшеліктері қарастырылды. Семиотикалық талдау өрнектер мен түстердің символдық мағыналарын түсіндіруге мүмкіндік берсе, салыстырмалы талдау ши тоқу өнерінің қазақтың басқа да сәндік-қолданбалы дәстүрлерімен ұқсастықтарын анықтауға бағытталды. Ал этнографиялық материалдар қазіргі қолөнер тәжірибелері туралы мәлімет алуға мүмкіндік берді. Зерттеу нәтижелері ши тоқуда кеңінен қолданылатын негізгі ою-өрнек мотивтерінің «Қошқармүйіз», «Сынық мүйіз», «Құс қанаты» және «Жұлдыз» сияқты элементтердің көркемдік және символдық мазмұнын талдауды көрсетеді. Бұл мотивтер зооморфтық, табиғи және космологиялық тақырыптарды бейнелейді және дәстүрлі түстік символикамен үйлесіп, қамыстан тоқылатын сызықтық құрылымға бейімделген. Сонымен қатар, сәндік өнердің басқа түрлерінен айырмашылығы ретінде, ши тоқудағы өрнек жүйесі тоқу техникасымен тығыз байланыста болып, көшпелі тұрмыс салтын, табиғатпен үйлесімді қатынасты және дүниетанымдық түсініктерді бейнелейтін мәдени код ретінде көрінеді. Зерттеу ши тоқу өнерінің мәдени жад пен дәстүрлі білімнің сақтаушысы ретіндегі маңызын айқындайды.

Түйін сөздер: ши тоқу, қазақтың сәндік өнері, ою-өрнек символикасы, түстер символикасы, қазақ ою-өрнегі, мәдени мұра, көшпелі мәдениет, дәстүрлі қолөнер.

Введение

Традиционные декоративные и прикладные искусства являются ключевой частью культурного наследия кочевых обществ в казахской культуре ремесла служили как практическим целям, так и символическим и художественным функциям, отражая мировоззрение, социальную структуру и духовные ценности народа. Среди различных традиционных ремесел особое место в материальной и художественной культуре казахов занимает плетение циновкой. Исторически плетеные тростниковые циновки были распространены в повседневной жизни кочевых народов и выполняли практические функции при строительстве и организации внутреннего пространства юрты, обеспечивая теплоизоляцию и структурную поддержку, а также добавляя декоративные элементы. Плетение циновкой развилось в изысканную форму искусства и объединило орнаментальный дизайн, цветовую символику и текстильные техники в сложную эстетическую систему. Этнографические источники отмечают различные типы циновок такие как «ак ши», «ойрама ши» и «шим ши», которые играли как функциональную, так и декоративную роль в традиционных кочевых жилищах.

В казахском декоративно-прикладном искусстве орнамент неизменно был связан с символическими значениями, отражающими космологические представления, социальные ценности и связь человека с природой. Цвета в традиционном орнаменте имели определённые значения: синий символизировал небо и божественную силу, белый чистоту и истину, красный жизненную силу и энергию, а зелёный обновление и природу. Декоративные ремесла имеют важную при сохранении культурной памяти и национальной идентичности, так как традиционные ремесла несут исторические знания, а также практики, которые отражали культурное мировоззрение. В этом контексте изучение ткачества циновкой даёт ценное представление о развитии казахских художественных традиций и

более широкой системы декоративно-прикладной культуры Центральной Азии. Более того, современные исследования культурного наследия подчёркивают ценность традиционных ремесел как части нематериального культурного наследия. Декоративные ремесла выступают в качестве культурных маркеров, связывая исторические традиции с современной культурной идентичностью. В свете глобализации и культурных изменений сохранение и изучение традиционных ремесел приобретает еще большее значение. Несмотря на растущий академический интерес к казахскому декоративно-прикладному искусству, ткачество циновкой по-прежнему относительно мало изучено по сравнению с другими традиционными ремеслами, такими как ковроткачество, ювелирное дело или вышивка. Большинство существующих исследований сосредоточены на общих аспектах казахского декоративно-прикладного искусства и не дают подробного анализа символической структуры орнамента и цвета в циновке и данный пробел указывает на необходимость тщательного исследования художественных и символических характеристик ткачества циновкой как уникального аспекта казахской культуры. Исследование актуально, поскольку оно направлено на анализ символики орнамента и цвета в казахском ткачестве циновкой и это важный элемент декоративно-прикладного искусства, дающий представление о мировоззрении, эстетических ценностях и символической системе традиционного казахского общества (Шайгозова 99).

Цель исследования заключается в анализе применения орнаментов в чиеплетение и из символической роли и значимости цветочных элементов. Данные аспекты рассматриваются как мотивы казахской культуры, которые являются важной частью декоративно-прикладного искусства и отражает культурные ценности казахского общества.

Исследовательский вопрос: *каковы основные орнаментальные узоры и какие символические значения связаны с цветами в визуальной системе чиеплетения?*

Обзор литературы

Декоративное искусство в традиционных обществах представляет собой не только материальное производство, но и системы, передающие культурные смыслы, социальные ценности и коллективные мировоззрения. Исследователи культурного наследия подчеркивают, что традиционные ремесла играют решающую роль в передаче культурных знаний и идентичности из поколения в поколение (Gibson 451), (Kasenova 7). Декоративные предметы хранят историческую память и социальный опыт, демонстрируя связь между окружающей средой, материальной культурой и эстетическими традициями конкретного общества (Khazbulatov 265). Таким образом, изучение традиционных ремесел, таких как ткачество, помогает нам понять, как культурные смыслы заложены в художественной практике. С точки зрения культурной антропологии, традиционные ремесла связаны с повседневной жизнью и социальной организацией (Khazbulatov 265). В кочевых культурах материальные предметы были не просто функциональными вещами, а также служили символами социальной идентичности и культурных ценностей. Ученые отмечают, что традиционное декоративное искусство часто возникает из специфических социально-экономических условий и визуально выражает коллективный культурный опыт. В истории искусства орнамент рассматривается как ключевая часть декоративного искусства. Орнаментальные композиции выступают в роли визуальных языков, передающих символические значения и культурные коды (Kuzembayev 259). Исследования центральноазиатских художественных традиций показывают, что орнамент представляет собой структурированную систему знаков, отражающую космологические представления и культурные концепции, укоренившиеся в мировоззрении традиционных обществ. Семиотические подходы к анализу орнамента также важны в этой исследовательской структуре. Орнамент можно рассматривать как систему визуальных символов, передающих культурную информацию и значения. Ученые, изучающие семиотику декоративно-

прикладного искусства, утверждают, что узоры, мотивы и структуры образуют сложные символические системы, выражающие социальные и космологические идеи посредством визуальных форм. Кроме того, современные исследования культурного наследия подчеркивают, что традиционные ремесла играют жизненно важную роль в нематериальном культурном наследии. Исследования по сохранению наследия показывают, что традиционные ремесленные практики включают в себя технологические знания, эстетические принципы и символические значения, которые способствуют культурной преемственности и формированию идентичности.

В центральноазиатских декоративных традициях символика цвета имеет решающее значение для эстетической структуры традиционных ремесел и символические значения являются центральными для визуального языка традиционных декоративных предметов. В частности, в казахском декоративно-прикладном искусстве плетение циновкой уникальная практика, сочетающая функциональность с орнаментальным и символическим выражением. Первоначально использовавшиеся в юртах и для украшения, плетеные тростниковые циновки эволюционировали в сложные декоративные предметы со сложными узорами и цветами. Исследования также подчеркивают роль традиционных ремесел в сохранении культурной идентичности в условиях глобализации. Исследования постсоветских обществ показывают, что культурные практики и традиционные ремесла остаются важными маркерами национальной идентичности и культурного наследия (Далланьол З).

Методы исследования

В исследовании применяются искусствоведческий анализ, семиотическая интерпретация и сравнительный анализ, что позволяет исследовать декоративное искусство не только как материальные объекты, но и как культурные выражения, демонстрирующие символические значения и эстетические ценности, присущие традиционным ремесленным практикам. Анализируется визуальная и композиционная структура чиеплетения, а также изучаются методы и художественные особенности традиционных орнаментов, такие как их геометрическое расположение, ритмические узоры и стилистические черты. Также в ходе исследования проведен семиотический метод для интерпретации символических значений в сочетаниях орнамента и цвета, встречающихся в ткачестве ши. В традиционной казахской культуре орнаментальные узоры служат символическим языком, выражающим культурные ценности, космологические идеи и социальные концепции. Семиотический анализ раскрывает более глубокие смыслы орнаментальных мотивов и цветовой символики, отражающие традиционные верования и мировоззрение кочевого общества. В частности, цвета в казахском орнаменте имеют специфические ассоциации с природными элементами, космологией и духовной символикой. Сравнительный метод анализирует сходства и различия между орнаментальными традициями в чиеплетении и другими казахскими декоративными ремеслами, такими как ковроткачество, войлокоделие и вышивка. Исследование также включает этнографический анализ, основанный на полевых материалах и интервью с современными ремесленниками, занимающимися традиционными ремеслами. Этнографические данные обеспечивают более глубокое понимание того, как орнаментальная символика и цветовые традиции передаются внутри ремесленных сообществ и как современные мастера интерпретируют эти значения.

В ходе анализа были выбраны четыре орнаментальных мотива, распространенных в традиционном чиеплетении, которые представляют собой наиболее часто используемые узоры в декоративном ткачестве из тростника и отражают символическую и эстетическую систему казахского декоративно-прикладного искусства. Анализируемые орнаменты включают следующие элементы:

- Қошқармүйіз;
- сынық мүйіз;

- құс қанаты;
- жұлдыз.

Данные орнаментальные элементы были выбраны поскольку они часто встречаются в традиционных декоративных композициях, используемых в шим-ши и орама-ши, которые служат как для внутренней отделки, так и в качестве структурных элементов юрты. Анализ сосредоточился на трех основных аспектах:

1. Семантическое значение, отражающее символические ассоциации в традиционной казахской культуре.
2. Цветовая символика, включающая использование красного, черного, белого, зеленого и синего цветов, связанных с космологическими и культурными значениями.
3. Композиционная структура, включающая симметрию, повторение и геометрическую организацию в орнаментальном дизайне.

Символическое значение этих орнаментов тесно связано с космологическим мировоззрением и культурными традициями казахского кочевого общества. Также четыре выбранных орнаментов обеспечивают прочную основу для анализа символических и эстетических особенностей орнамента и цвета.

Результаты

Результаты исследования показывают структурные и символические особенности орнаментальных мотивов, используемых в традиционном казахском ткачестве циновкой, которые отражают символическую и эстетическую систему казахского декоративно-прикладного искусства. Выбранные орнаменты демонстрируют связь между художественной формой, культурной символикой и традиционным мировоззрением, присутствующим в визуальной культуре казахского народа. Исследованные орнаментальные мотивы включают четыре элементов (см. таблицу 1).

Таблица 1. - Описание выбранных орнаментальных мотивов в казахском искусстве чиеплетен

Орнамент	Визуальные характеристики	Символическое значение	Функция в композиции
Қошқармүйіз	Орнамент в виде изогнутых рогов, образующих симметричные спиралевидные линии	Символ достатка, силы и плодородия, связанный с традиционной скотоводческой культурой казахов	Часто используется как центральный композиционный элемент
Сынық мүйіз	Орнамент, основанный на мотиве «ломаного рога», состоящий из угловатых и изогнутых линий	Символизирует непрерывность жизненного пути и трансформацию	Используется в ритмически повторяющихся композициях
Құс қанаты	Удлиненный орнамент, напоминающий форму птичьего крыла	Ассоциируется со свободой, движением и связью человека с природой	Используется как второстепенный декоративный элемент, формирующий линейные композиции
Жұлдыз	Геометрический орнамент звездообразной формы	Символ космического порядка, небесной гармонии и ориентации в пространстве	Часто используется как повторяющийся орнаментальный мотив

Мотивы в каждом из орнаментов обозначает определенную символическую идею, связанную с культурными взглядами кочевого общества и включает в себя такие понятия, как процветание, защита, гармония с природой и космологический порядок (Suraganov, 99). Анализ показывает, что орнаментальная система чиеплетения основана на взаимосвязи между геометрическими формами, символическими мотивами и традиционными цветовыми схемами. Вместе эти элементы создают единую художественную систему, отражающую культурную самобытность и эстетические ценности казахского декоративно-прикладного искусства.

Кошкармуиз является одним из наиболее распространенных элементов в казахском декоративно-прикладном искусстве, включая чиеплетение и состоит из двух симметрично изогнутых спиралей, напоминающих рога барана (Suraganov, 100). В символике кочевых культур баран символизирует процветание, жизненную силу и богатство, связанные с животноводством и мотив служит не только декоративным элементом, но и символом экономических и культурных основ казахского кочевого мировоззрения.

В дизайне орнамента четко прослеживается принцип двусторонней симметрии, характерный для многих тюркских орнаментальных стилей, где спирали рогов барана создают живой визуальный ритм, сохраняя при этом общий баланс. В центре мотива находится ромбовидный элемент, который в символике казахского орнамента часто символизирует плодородие, изобилие и материальное богатство и выступает в качестве центрального элемента композиции, визуально стабилизируя структуру и усиливая смысл процветания и благополучия (Kasenova 7). Цвет играет важную роль в интерпретации

орнамента, так в примере используются три основных цвета. В традиционной казахской цветовой символике красный цвет связан с жизненной энергией, жизненной силой и мощью (Kuzembaev 261).



Рисунок 1. - Орнамент «Қошқармұйіз» в традиционном казахском ткачестве ши: композиционная структура и символика цвета

Далее черный представляет землю, стабильность и защиту, подчеркивая связь между человеческой жизнью и природой. Желтый, часто ассоциируемый с солнцем и золотом, символизирует плодородие, процветание и изобилие. Сочетание этих цветов создает единую символическую палитру, которая усиливает смысл, заложенный в орнаментальном мотиве. С семиотической точки зрения, мотив Кошкармуиз служит культурной знаковой системой, где форма, цвет и композиция работают вместе, чтобы выразить символические идеи и повторяющееся появление в чиеплетении показывает его важность как культурного кода, передающего темы процветания, защиты и преемственности в традиционном казахском мировоззрении (Шайгозова 98).

Мотив Кошкармуиз демонстрирует, как орнамент связан с процветанием, животноводством и космологическим равновесием посредством изогнутых спиралевидных форм. Казахская орнаментальная традиция также включает в себя узоры, созданные путем угловых изменений одной и той же символики рога, где узоры демонстрируют как преемственность в орнаментальной системе, так и эволюционный характер визуальных форм. Ярким примером этого изменения является орнамент «Сынык Муиз», где изогнутый бараний рог переосмыслен с использованием ломаных, угловатых линий и переход от спиралевидных к угловатым формам показывает многогранность орнаментального языка и иллюстрирует, как традиционные символы включаются в различные схемы ткачества ши (см. рисунок 2).



Рисунок 2. - Орнамент «Сынық мүйіз» в традиционном казахском ткачестве ши: геометрическая трансформация мотива рога

В отличие от плавных спиральных изгибов орнамента «Кошкармуиз», узор «Сынық мүйіз» состоит из угловатых, ломаных линий, создавая более геометрическую и ритмичную визуальную структуру, изменение отражает гибкий характер традиционного орнамента, где символические формы переосмысливаются в соответствии с композиционными потребностями и эстетическими вкусами (Suraganov 99). Структурно мотив основан на повторяющемся зигзагообразном узоре, который обеспечивает непрерывный орнаментальный ритм по всей поверхности ткани и повторение создает визуальное движение и подчеркивает горизонтальную структуру, типичную для ши-ткачества. Угловым дизайном мотива также добавляет ощущение динамики, предполагая изменение, непрерывность и циклическое обновление в символическом языке казахского декора. Значение мотива «Сынық мүйіз» связано с более широкой системой символов, основанных на роге. В традиционной кочевой культуре изображение рога символизирует жизненную силу, мощь и процветание, связанные с пастушеской жизнью. Однако в своей ломаной или угловатой форме этот мотив может также представлять собой перемены, адаптацию и преемственность культурных традиций из поколения в поколение. Цветовая символика также играет важную роль в композиции. В этом примере доминирующими цветами являются зеленый, оранжевый и белый. В традиционной цветовой палитре казахского декоративного искусства зеленый часто символизирует природу, обновление и гармонию с окружающей средой. Оранжевый символизирует тепло, энергию и жизненную силу, усиливая динамичный визуальный ритм мотива. Белый, обычно рассматриваемый как символ чистоты и света, служит уравнивающим фоном, который проясняет структуру орнамента. С семиотической точки зрения, орнамент «Сынық Мүйіз» можно рассматривать как визуальную трансформацию архетипического символа. Превращая изогнутый мотив бараньего рога в угловатые геометрические формы, орнамент показывает, как традиционные символы развиваются в рамках декоративных систем, сохраняя при этом свое культурное значение (Yussupova 197).

В то время как ранее проанализированные мотивы демонстрируют символические изменения в орнаментации на основе рога в казахском декоративно-прикладном искусстве, орнаментальная система традиционного ткачества ши также включает мотивы, вдохновленные животными, особенно птицами, и миром природы. Такие мотивы расширяют значение орнаментального языка, вводя идеи, связанные со свободой,

движением и связью между человеком и природой. Ярким примером этой символической группы является орнамент кус-канаты, который визуально представляет форму птичьего крыла в дизайне ткачества ши (см. рисунок 3).

На рисунке 3 представлен традиционный казахский орнамент «Кус канаты» что означает «крыло птицы». Орнамент является частью группы анималистических орнаментов, встречающихся в искусстве казахского народа и отличается симметрично изогнутыми формами, напоминающими стилизованные крылья, отходящие от центральной оси. Компонировка создает ощущение баланса и гармонии, а также намекает на движение и энергию в дизайне. Символическое значение мотива «Кус канаты» связано с тем, как птицы



Рисунок 3. Орнамент «Құс қанаты» в традиционном казахском чиеплетении: символика крыла птицы и цветовая семантика

воспринимаются в традиционных верованиях казахской кочевой культуры. Птицы рассматривались как символы свободы, духовного роста и связи между землей и небом (Tlegenova 7). Мотив крыла символизирует стремления, движение и гармонию с природой и вписывается в линейный узор плетеной поверхности тростника, типичный для плетения ши. Симметричное расположение форм крыльев вдоль горизонтальной оси добавляет визуального ритма орнаменту, обеспечивая при этом стабильность декоративного дизайна. Такая компоновка позволяет мотиву служить одновременно визуальным элементом и символом (Шайгозова 5).

Ранее проанализированные орнаментальные мотивы иллюстрируют символические изображения животных и птиц в визуальном языке казахского декоративно-прикладного искусства, орнаментальная система традиционного ткачества ши также включает космологические мотивы, отражающие кочевое восприятие Вселенной и небесного порядка. Такие мотивы расширяют символическое значение орнамента за пределы изображений природного мира и вводят элементы, связанные с космической гармонией и ориентацией в пространстве. Одним из наиболее характерных примеров этой символической группы является орнамент Жұлдыз, который визуальнo представляет образ звезды и занимает важное место в композиционной структуре казахского орнаментального искусства (см. рисунок 4).

Орнамент построен вокруг центральной многоконечной звезды, которая является

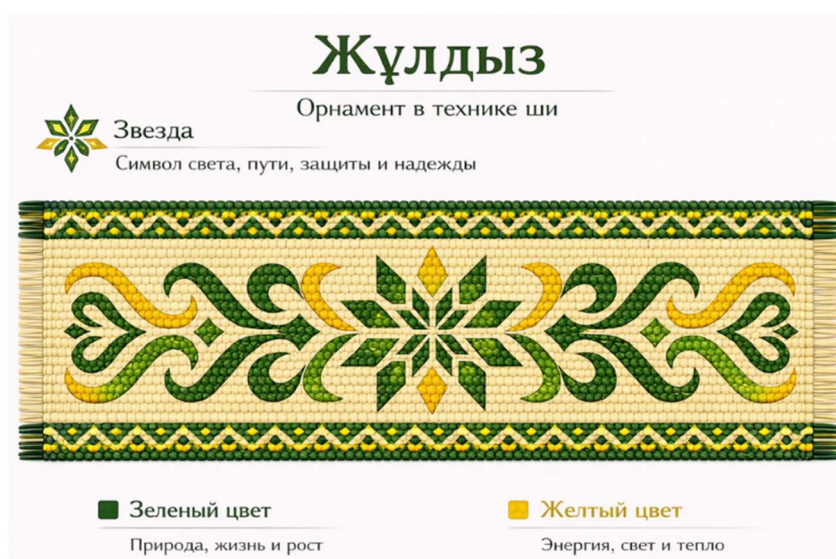


Рисунок 4. - Орнамент «Жұлдыз» в традиционном казахском чиеплетении: космологическая символика звезды и цветовая семантика

главным элементом декора. Звездный мотив часто состоит из симметричных геометрических фигур, расходящихся от центра и радиальная симметрия создает сбалансированное визуальное оформление и подчеркивает центральную роль звезды как символа космической гармонии и порядка (Shaygozova 120). В плетении ши мотив Жұлдыз обычно встраивается в линейную структуру плетеной поверхности тростника, сохраняя при этом радиальный дизайн. Окружающие орнаментальные элементы часто обрамляют центральную звезду, создавая ритмичный узор, который усиливает визуальную значимость мотива. Композиция отражает традиционные принципы казахского орнамента, где центральные мотивы обычно представляют ключевые космологические идеи. Значение орнамента «Жұлдыз» тесно связано с символическим значением звезд в кочевом мировоззрении. Исторически звезды рассматривались как источники света, руководства и защиты и часто символизируют надежду, защиту, ориентацию и духовное просветление в казахском декоративно-прикладном искусстве (Ulbossyn 101). С семиотической точки зрения, мотив «Жұлдыз» можно рассматривать как визуальное представление космического порядка в казахском декоративно-прикладном искусстве. Благодаря радиальному дизайну, символическому значению и тщательно подобранным цветам, орнамент передает темы гармонии, руководства и духовного равновесия, глубоко укоренившиеся в культурном мировоззрении казахского народа.

Обсуждение

Анализ четырех выбранных орнаментальных мотивов показывает, что орнаментальная система традиционного казахского ши-ткачества является не просто декоративной техникой, а служит сложным символическим языком, отражающим культурное мировоззрение кочевого общества (см. таблицу 2).

Таблица 2. - Культурное и символическое значение анализируемых орнаментов в казахском чиеплетении

Орнамент	Культурное происхождение	Символическая область	Культурное значение в казахском мировоззрении	Роль в композиции чиеплетения
Қошқармүйіз	Зооморфная символика пастушеской культуры	Символика животных	Символизирует благополучие, силу, плодородие и достаток, связанные с традиционным скотоводством	Центральный композиционный мотив, формирующий декоративный ритм
Сынық мүйіз	Трансформация орнамента «рог»	Символика динамической трансформации	Олицетворяет непрерывность жизненных циклов и преобразование традиционных форм	Повторяющийся мотив, создающий ритмическое движение в композиции
Құс қанаты	Зооморфные образы птиц	Природная символика	Ассоциируется со свободой, духовным возвышением и гармонией человека с природой	Линейный орнамент, формирующий плавную декоративную структуру
Жұлдыз	Космологическая символика	Небесная (космическая) символика	Символизирует космический порядок, ориентир, защиту и связь человека со Вселенной	Центральный геометрический мотив, организующий декоративное поле композиции

В отличие от текстильной вышивки или ковроткачества, где орнамент выступает в качестве независимого декоративного слоя, в чиеплетение орнамент возникает непосредственно в процессе ткачества. Декоративные мотивы формируются посредством ритмичного связывания окрашенных стеблей тростника цветными нитями, что означает, что структура орнамента тесно связана со структурной логикой тканой поверхности. В этом контексте изученные мотивы Кошкармуиз, Сыныг муиз, Құс қанаты и Жұлдыз показывают,

как традиционные казахские ремесленники формировали символические формы, чтобы они соответствовали линейному дизайну тростникового ткачества. Вытянутый горизонтальный формат ковриков ши требует, чтобы орнаменты располагались таким образом, чтобы поддерживать стабильность тканой структуры, создавая при этом визуальный баланс на поверхности.

Например, мотив Кошкармуиз, традиционно связанный с символикой рога, становится структурной частью коврика, организуя его центральную декоративную ось. Изогнутые линии мотива соответствуют плавным переходам между пучками стеблей тростника, позволяя мастерам создавать гладкие орнаментальные формы в рамках жесткой линейной структуры материала. Аналогично, мотив «Сыныг муиз» демонстрирует, как мастера адаптируют орнаментальные формы к техническим ограничениям ткачества. Угловые сегменты этого мотива соответствуют ступенчатым переходам, образованным обматыванием цветных нитей вокруг отдельных стеблей тростника и означает, что орнамент не только несет символическое значение, но и отражает техническую логику процесса ткачества.

В традиционных казахских интерьерах циновки «ши» выполняли как функциональные, так и декоративные функции и служили в качестве настенных покрытий, перегородок внутри юрты и декоративных элементов в жилых помещениях. Поэтому орнаментальный дизайн циновки «ши» создавался не только для красоты, но и для организации пространства внутри юрты. Исследованные орнаменты показывают, как мастера структурировали визуальные элементы дизайна для улучшения пространственного восприятия тканых изделий. Например, мотив «Құс қанаты» представляет собой длинные, плавные формы, визуально растягивающиеся вдоль горизонтальной оси циновки. Такая ориентация подчеркивает ширину плетеной поверхности и усиливает визуальную целостность интерьера. Напротив, мотив «Жұлдыз» обычно выступает в качестве центрального элемента в орнаментальной структуре радиальная форма выделяется на фоне преимущественно линейного расположения тростникового полотна, создавая визуальный якорь в дизайне. Чиеплетение не просто при использовании так как часто ее форма вытянутая и часто орнаменты позволяют сбалансировать эту форму, а также визуально украшает пространство.

Также орнаменты при работе с тростником нельзя просто так применить, так как природные свойства тростника весьма специфичные, и выложить нужные рисунки гораздо тяжелее чем в других материалах. Данная сложность связана с тем, что стебель тростника имеет свою естественно линию и они более жесткие, что сильно влияет на визуальное восприятие рисунка. Следовательно, орнаментальные мотивы в плетении циновки часто фокусируются на симметрии, повторении и линейном ритме. Выбранные орнаменты демонстрируют, как мастера превращали символические формы в узоры, соответствующие природным характеристикам материала. Изогнутые мотивы упрощаются до модульных форм, а геометрические орнаменты выравниваются с вертикальной структурой стеблей тростника и процесс иллюстрирует, как культурные символы выходят за физические пределы материала (Yussupova 197). С более широкой культурной точки зрения, включение этих орнаментальных мотивов в плетение ши подчеркивает роль ремесла как носителя культурных знаний и художественных традиций. Орнаменты выбираются не случайно, а тщательно отбираются и располагаются в соответствии с традиционными эстетическими правилами, передаваемыми из поколения в поколение. Присутствие зооморфных, природных и космологических мотивов в одном тканом изделии показывает, как плетение ши служит визуальным сочетанием различных символических областей в казахской культуре. Благодаря сочетанию структуры материала, методов плетения и символического орнамента, коврики ши становятся чем-то большим, чем просто практичными предметами

они воплощают художественное мировоззрение казахского народа. Изученные орнаменты указывают на то, что ткачество ши следует рассматривать не только как декоративное ремесло, но и как материальное выражение культурной идентичности, где традиционные знания, эстетические ценности и символические значения сходятся в тканом изделии.

Заклучение

Результаты показывают, что орнаментальная структура ткачества ши образует четкую символическую систему и форма, цвет и техника работают вместе, создавая осмысленный визуальный язык. Анализ выбранных мотивов, таких как Кошкармуиз, Синыг муиз, Кус канаты и Жулдыз, показал, что каждый орнамент символизирует ключевые аспекты традиционного казахского мировоззрения. Роговые мотивы иллюстрируют пастушеские корни кочевой жизни и представляют процветание, жизненную силу и преемственность. Мотив птичьего крыла символизирует свободу и гармонию с природой. Мотив звезды символизирует космический порядок, руководство и духовное равновесие, которые отражают сочетание зооморфной, природной и космической символики в декоративной системе ткачества ши. Результаты также подчеркивают уникальную роль орнамента в технической структуре ткачества из тростника. В отличие от многих других видов декоративного искусства, где орнамент добавляется к готовой поверхности, орнаментальные узоры в ткачестве ши возникают непосредственно в процессе ткачества. Ритмичное переплетение цветных нитей вокруг стеблей тростника создает как структурные, так и декоративные элементы изделия. Поэтому орнамент в ткачестве ши следует рассматривать не только как визуальное украшение, а также продукт ремесленной техники и материальных качеств тростника. Исследование подтверждает, что цветовая символика имеет решающее значение для усиления смысла орнаментальных мотивов и наряду с геометрической структурой и символическими мотивами, цвет помогает сформировать целостную эстетическую и культурную систему в рамках ремесленной традиции. На основе этих результатов исследовательская цель была достигнута и в исследовании были определены основные орнаментальные мотивы в традиционном ткачестве ши и интерпретированы их символические значения в контексте казахского декоративно-прикладного искусства. Также ответ на исследовательский вопрос показывает, что визуальная система ткачества ши организована вокруг набора культурно значимых мотивов, представляющих пасторальную жизнь, природную среду и космические идеи. Связанные с ними цвета усиливают значения жизненной силы, защиты, гармонии и духовного порядка.

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Philological Sciences

THE STRUCTURAL AND SEMANTIC ANALYSIS OF THE LITERARY TEXT

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Abstract

The literary text has been analysed from the viewpoint of various categories, including the analytical and interpretational elements. Meanwhile, the semantic characteristics as well as the structural aspects are considered the essential ones for reflecting the rare and unique features of the author. When analyzing the text, the reader is able to define the method of characterization, the peculiar narrative style, explicit and implicit lexical patterns, and specific syntactical structures.

The following fragments comprise the variety of activities based on the short story "The Canterville Ghost" by Oscar Wilde. The activities focus on the comprehensive analysis of the fiction for the 2nd –year students (Intermediate Level).

Chapter 1

Paraphrase the parts in italics:

1. The laws of Nature are not going *to be prevented from being used* for the British aristocracy.
2. *Your positions are based on human reasons* in America.
3. We would *find the ghost the proper place*.
4. Lord Canterville was *the highly responsible person*.
5. We *do not have enough courage* to live in the place ourselves.

Give the account of the following:

- 1) The victims of the ghost's evil actions and the consequences;
- 2) The Minister's attitude to ghosts;
- 3) The description of Mrs Otis;
- 4) The profile of Washington, the elder son;
- 5) The description of Miss Virginia Otis;
- 6) The description of the nature and the weather on the symbolic level.

Answer the following questions using the words and word combinations in italics.

- 1) Is it always easy *to stick to the point*? When do people *beat about the bush* instead of *sticking to the point*?
- 2) What do you generally say when you *run into someone* you haven't seen for a long time?
- 3) Who do you call *a welcome guest*?
- 4) Do you always *lose your patience*? In what cases do you *lose your patience*?
- 5) People feel *miserable* when they are cold, don't they?
- 6) What kind of meal is meant if we call it *miserable*?
- 7) What do you mean saying that a person *has a sharp tongue*?
- 8) When are people generally *tongue-tied*?
- 9) Is it polite *to fix one's eyes on a person*?

- 10) Are all the people *pleasant in their ways* really pleasant people, nice to deal with?
- 11) What do people mean when they say that they *wash their hands of the matter*?
- 12) People should live *within their means*, shouldn't they?
- 13) What do you want *in your heart of hearts to do/to be*?

Chapter 2

Study the following sentences and answer the questions referring to them:

1) The whole family were now quite interested; Mr. Otis began to suspect that he had been too dogmatic in his denial of the existence of ghosts, Mrs. Otis expressed her intention of joining the Psychical Society, and Washington prepared a long letter to Messrs. Myers and Podmore on the subject of the Permanence of Sanguineous Stains when connected with Crime.

- How did Mr Otis change his mind about the ghost?
- What was Mrs Otis's interest in ghosts transformed into?
- What was Washington's letter about?

2) The subjects discussed, as I have since learned from Mr. Otis, were merely such as form the ordinary conversation of cultured Americans of the better class, such as the immense superiority of Miss Fanny Davenport over Sara Bernhardt as an actress; the difficulty of obtaining green corn, buckwheat cakes, and hominy, even in the best English houses; the importance of Boston in the development of the world-soul; the advantages of the baggage check system in railway travelling; and the sweetness of the New York accent as compared to the London drawl.

- What was the attitude to Sara Bernhardt?
- What was the preference in food?
- What is the importance of Boston?
- Did the family get annoyed with the London accent?

Chapter 3

Match the words/ word combinations to their definitions:

1. To decline	To look at sb in an angry way
2. At length	Made in the shape of an arch or a series of arches; having a ceiling or roof of this shape
3. Renewal	Famous and respected
4. To detach	To lose control of your feelings and start crying
5. To discharge sth on sb	To refuse politely to accept or to do sth
6. To attain	To graze// to rub the skin off your knee by falling
7. To extinguish	To remove sth from sth larger
8. Tincture	Worry and anxiety that you show by behaving in a nervous way
9. Vaulted	Producing a faint light in the dark
10. A remedy	For a long time
11. To glare at sb	To spend time in a pleasant lazy way
12. An accomplishment	A substance dissolved in alcohol for use as a medicine
13. Renowned	Making you feel tired and bored
14. Phosphorescent	To put out// to make a fire stop burning or a light stop shining
15. To break down	To fire a gun
16. Agitation	A skill or special ability// an impressive thing that is achieved after a lot of work
17. Weary	A treatment or medicine to cure a disease or reduce pain
18. To bark	To succeed in getting sth, usually after a lot of effort
19. To while away	A situation in which sth begins again after a pause

Are the sentences True or False? Correct the false ones.

- 1) The Canterville ghost didn't leave his room during his illness.
- 2) The ghost made his choice on a short pointed knife.
- 3) He decided to take his revenge on Washington, performing the murderous scene.
- 4) The ghost was planning to reveal the secrets of all the corpses of his kin.
- 5) The ghost bore his grudge on Virginia.
- 6) He had a range of characters for the twins.
- 7) The Otis family were undisturbed by the outside sounds.
- 8) The ghost was in high spirits and anticipated the night.
- 9) While making his way, the ghost was murmuring the song.

Paraphrase the following:

- 1) These kaleidoscopic changes naturally amused the party very much, and bets on the subject were freely made every evening.
- 2) The twins, having brought their pea-shooters with them, at once discharged two pellets on him, with that accuracy of aim which can only be attained by long and careful practice on a writing-master.
- 3) On reaching the top of the staircase he recovered himself, and determined to give his celebrated peal of demoniac laughter.
- 4) He had hoped that even modern Americans would be thrilled by the sight of a Spectre In Armour.
- 5) He had been highly complimented on his suit by no less a person than the Virgin Queen herself.

Give the situations from the text with the phrases:

- 1) To do the personal injury;
- 2) To burst into sth;
- 3) To excite sb's attention;
- 4) To make the bets;
- 5) To be distressed;
- 6) A suit of armour;
- 7) In accordance with sth;
- 8) A wild shriek of rage;
- 9) The peal of laughter;
- 10) To make preparations for sth;
- 11) To content oneself with sth/ doing sth;
- 12) To become a prey to sth;
- 13) The suit of mail;
- 14) Out of respect for sb;
- 15) To be complimented on sth;
- 16) To be overpowered by sth

Study the following patterns and give your own examples:

- 1) *Hardly had* the fearful echo died away *when* a door opened, and Mrs Otis came out in a light blue dressing-gown.
- 2) *What really distressed him most was*, that he had been unable to wear the suit of mail.
- 3) *It was he who was* in the habit of removing the blood-stain.
- 4) *No sooner had he done so, than* he fell back.

Give the account of the following:

1. The reason for Mr Otis's annoyance in the morning and his decision about the noise.
2. The kaleidoscopic changes of the stain.
3. A fearful crash in the hall on Sunday night.
4. Mrs Otis's disturbance in the Ghost's performance.
5. The Ghost's suit of mail.

Chapter 4

Answer the following questions:

1. How did the ghost feel the next day?
2. What made him remove the blood-stain on the library floor?
3. What was he obliged to do as a ghost?
4. What precaution did he take?
5. What mixed feelings did he have while using the Rising Sun Lubricator?
6. What traps were set for the ghost?
7. Did he manage to escape the traps?
8. Did he eventually put up with his position in the house?

Chapter 5

Define the meaning of the parts in italics:

1. Empty houses quickly take on a *forlorn* look.
2. She waited *in the forlorn hope* that he would one day come back to her.
3. Do you *fancy* going out this evening?
4. He started to chat to me and I could tell that he really *fancied himself*.

5. She *fancied* that she heard footsteps behind her.
6. She said she wanted a dog but it was only *a passing fancy*.
7. I was still *foot-loose and fancy-free* in those days.
8. Jane has a *wicked* sense of humour.
9. The rejection was a *wicked* blow to her pride.
10. He *made it plain that* we should leave.
11. *The plain fact is* that nobody really knows.
12. She had no right to interfere in what was *plainly* a family matter.
13. She was *plainly* dressed and wore no make-up.
14. That one mistake *ruined* his chances of getting the job.
15. If she loses the court case it will *ruin* her.
16. The scandal left his reputation *in ruins*.
17. They met *by pure chance*.
18. His motives were *pure*.
19. She took the job *purely and simply* for the money.
20. Those benefits still *prevail* among certain social groups.
21. Fortunately, common sense *prevailed*.
22. The *prevailing* view seems to be that they will find her guilty.
23. I *clutched* on to the chair for support.
24. Fear *clutched* at her heart.
25. He managed to escape *from* their *clutches*.
26. Without another word she *swept* out of the room.
27. A wave of tiredness *swept over* her.
28. Rumours of his resignation *swept through* the company.
29. All their advice was *swept aside*.
30. They were *swept along* by the force of their emotions.

Speak on the topics:

1. The ghost's attitude to his origins;
2. The ghost's future prospects on moving to New York;
3. The ghost's difficulty with sleeping;
4. The Garden of Death;
5. The ghost's attitude to death;
6. The meaning of the prophecy;
7. Warnings for Virginia before her disappearance

Chapter 6

Study the following patterns and give your own examples:

On arriving at the spot, he found that the gypsies had gone.

Having sent off Washington, he ran home.

If you had let us be engaged last year, there *would never have been* all this trouble.

If you won't go back I suppose *you must come* with me.

Assessment on 'The Canterville Ghost' by Oscar Wilde

Explain the meaning of the phrases:

1. To be at peace with oneself
2. To shut oneself away from the world
3. To stand motionless in natural indignation
4. A martyr to nervous disorders

5. To be rattled by the question
6. To excite a good deal of comment
7. To be an excellent remedy
8. To assert one's dignity and social position
9. To lay down with a severe cold
10. To give sb a free passage

Explain the meaning of the phrases:

1. To cry out like a trapped animal
2. To weep like a lost child
3. To do sth passionately
4. To play a practical joke on sb
5. To leave one's side
6. To comply with sb's request
7. To shake one's hand cordially
8. The hideous garment
9. To grapple with sb
10. To be more than sufficient

Analyse the following:

1. Chapter 1. The discussion of different subjects. The profiles of the Otis family.
2. Chapter 1. The way to Canterville Chase. The welcome of the Otis family.
3. Chapter 2. The permanence of the blood-stain. The subjects discussed at supper. The offer of the Rising Sun Lubricator.
4. Chapter 2. The gross insult of the Ghost. The recollections of the ghost's performances and victims.
5. Chapter 3. The second appearance of the Ghost.
6. Chapter 3. The third attempt to frighten the Otis family.
7. Chapter 3. The sinister symbols of the night. A horrible spectre.
8. Chapter 3. The strange transformation of the spectre. The vain oath and baffled purpose.
9. Chapter 4. Shattered nerves and eventual traps.
10. Chapter 4. The ruined performance. The remarkable impersonation. The panic attack.
11. Chapter 4. The abandoned nocturnal expeditions. The distant relative.
12. Chapter 5. The extreme depression of the Canterville Ghost and Virginia's feeling of pity for him. The conversation between the Canterville Ghost and Virginia.
13. Chapter 5. The conversation about the emigration and the problem with sleeping. The old prophecy.
14. Chapter 6. The disappearance of Virginia. The search for Virginia.
15. Chapters 6 and 7. The Ghost's hidden place. The funeral.
16. Chapter 7. The interview on the subject of jewels. Virginia's marriage. Her gratitude to the Ghost.

The thorough structural and semantic analysis can alternatively be completed with the scheme:

1. Say what you know about the author, their method, about the book from which the analysed extract is taken.

2. Consider relations between the choice of words and the imagery, the emotional-evaluative tone, atmosphere of the text:
 - 1) Pick out the words conveying feelings, attitudes, images
 - a) inherently (due to their qualities in the system of language);
 - b) adherently (due to their contextual connotations: figurative meaning/metaphor, simile, epithet; ironic use – opposition of dictionary and contextual meanings; double meaning – actualization of two or several meanings; associatively rich lexical items – adjectives of colour, words, indicating natural phenomena, sounds, smells.
 - 2) Group the words on the basis of logical/thematic or stylistic equivalence or contrast.
 - 3) Point out the key words, key images, poetic details, associations. Try to create the images in your imagination.
 - 4) State if there are any cases of incongruity, exaggeration, parody, deviation from the norm, accumulation of details creating ironic/tragic effect.
3. Study the influence of the syntactic organization of the text on the emotional-evaluative aspect of its content through the rhythm, the tone and foregrounding of detail:
 - 1) Single out the syntactic meaning of foregrounding/repetition, inversion, parallelism, detachment;
 - 2) Consider the influence of the syntactic structure of the text on its rhythm (slack, energetic, stopped, monotonous, jerky, even/uneven);
 - 3) Define the influence of types of sentences on the rhythm, tone and the atmosphere of the text (joyful, oppressive, sinister, mystic, lyrical).
4. State the nature of relations between the peculiarities of the graphico-phonetic aspect of the text and its rhythm and tone:
 - 1) Consider the influence of vowels upon the rhythm (concentration of long vowels – slow, slack rhythm; concentration of short vowels – energetic rhythm);
 - 2) Define the influence of punctuation on the reader (dots/ellipsis, dashes, exclamatory/ interrogative marks);
 - 3) Consider the role of sound symbolism in creating the tone, in evoking pleasant/unpleasant associations.
5. Consider the angle of vision and its influence on the tone (panoramic angle of vision – elevated tone, philosophical implications, close-ups – lyrical/ironical tone).
6. Sum up your observations:
 - 1) Characterize the atmosphere/emotions and the tone/ attitude of description created by lexical, syntactic and graphico-phonetic peculiarities of the text;
 - 2) Characterize the implicit images of the author and the personages. What do you learn about the author's outlook, their attitude to the things and the people described? What do we learn about the personages' status of character, mood, habits, tastes through their appearance, clothes, manners, description of their homes and through their attitude to the surroundings?
 - 3) Define the aesthetic functions of the extract – to reveal the character's/ author's outlook, attitude, feelings;
 - 4) Express your opinion about the message of the extract/ about the adequacy/inadequacy of the form. Speak about individual peculiarities of the author's style.

The Role of Vocabulary Games in Second Language Acquisition Across Bloom's Revised Taxonomy

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ABSTRACT

Background: Vocabulary acquisition is widely recognised as a cornerstone of second language development, yet classroom instruction continues to rely heavily on decontextualised methods — translation lists, fill-in-the-blank drills, and rote memorisation — whose limitations are well-established in the second language acquisition (SLA) literature. **Methods:** This article synthesises four converging theoretical frameworks — Craik and Lockhart's depth-of-processing model, Krashen's Input and Affective Filter Hypotheses, Vygotsky's Zone of Proximal Development, and Hulstijn and Laufer's involvement load hypothesis — and maps six classroom vocabulary games systematically onto Anderson et al.'s Bloom's Revised Taxonomy of Educational Objectives. Each game is described in practical terms and analysed with respect to its cognitive demands, affective profile, and acquisition-theoretic justification. **Results:** The analysis demonstrates that the six games — Concentration, Word Association Chains, Taboo, Odd One Out, Vocabulary Auction, and Story Chain — address all six levels of Bloom's Revised Taxonomy (Remember, Understand, Apply, Analyse, Evaluate, Create) and collectively create the rich, repeated, emotionally engaged encounters with target vocabulary that the SLA literature consistently identifies with durable acquisition. **Conclusion:** When selected diagnostically and organised through Bloom's Revised Taxonomy, vocabulary games constitute a complete, theoretically grounded instructional pathway from first encounter to independent productive use — not a pedagogical supplement, but a primary instructional necessity.

Keywords: vocabulary acquisition, game-based learning, Bloom's Revised Taxonomy, depth of processing, second language acquisition, involvement load hypothesis

INTRODUCTION

Vocabulary is the foundation upon which all language use rests. As Wilkins famously observed, 'without grammar very little can be conveyed; without vocabulary nothing can be conveyed' [15]. Despite the centrality of lexical knowledge to communicative competence, vocabulary instruction in many classrooms continues to be dominated by approaches that are structurally ill-suited to the demands of durable acquisition: translation equivalents, isolated definition matching, and repetitive drills that engage learners at the shallowest levels of cognitive processing [10, 11]. The research record is consistent: such methods produce fragile, receptive-only knowledge that does not transfer to spontaneous communication [8].

The contrast with game-based vocabulary instruction is striking. A substantial and growing body of empirical research demonstrates that games create precisely the conditions the SLA literature identifies with durable lexical acquisition: repeated, meaningful, emotionally engaged, and cognitively demanding encounters with target vocabulary [9, 12]. Yet despite this evidence, games continue to be treated in many educational contexts as motivational rewards — 'fillers' deployed after the real instructional work is done — rather than as primary pedagogical instruments grounded in learning science [16].

This article addresses that disconnect by pursuing two related objectives. First, it locates game-based vocabulary instruction within four converging theoretical frameworks: Craik and Lockhart's depth-of-processing model [3], Krashen's Input and Affective Filter Hypotheses [6], Vygotsky's Zone of Proximal Development [13], and Hulstijn and Laufer's involvement load hypothesis [5]. Second, it maps six specific classroom games onto the six levels of Anderson et al.'s Bloom's Revised Taxonomy [1], providing a complete, evidence-based pathway from initial word recognition to independent productive use. The aim is to equip teachers not merely with a set of activities, but with the theoretical architecture needed to select, sequence, and justify game-based vocabulary instruction systematically.

MATERIAL AND METHODS

This article adopts a theoretical review and synthesis methodology. The primary sources are drawn from cognitive psychology, SLA theory, and educational taxonomy research. Four foundational theoretical frameworks are reviewed and applied: the depth-of-processing model (Craik & Lockhart, 1972) [3]; Krashen's Input and Affective Filter Hypotheses (1982) [6]; Vygotsky's Zone of Proximal Development (1978) [13]; and the involvement load hypothesis (Hulstijn & Laufer, 2001) [5]. These frameworks are then operationalised as evaluative criteria for six classroom vocabulary games, which are assessed with respect to their cognitive depth, affective profile, and social-interactional structure.

The six games are evaluated against Anderson et al.'s Bloom's Revised Taxonomy (2001) [1] — a hierarchical framework of six cognitive levels (Remember, Understand, Apply, Analyse, Evaluate, Create) — on the grounds that this taxonomy provides a practical and widely understood diagnostic tool for mapping instructional activities to learners' developmental needs. The games are selected to provide complete coverage of the taxonomy, yielding a coherent and scalable instructional sequence. Supplementary theoretical support is drawn from Nation [10], Schmitt [11, 12], Webb [14], Gardner [4], and Lantolf and Thorne [7].

2.1 Depth of Processing

Craik and Lockhart's depth-of-processing (DoP) framework proposes that the durability of a memory trace is determined by the depth of cognitive processing at encoding [3]. Shallow processing — such as copying a definition — leaves a weak, rapidly decaying trace. Deep processing — involving semantic elaboration, inference, and production — produces robust, long-term lexical representations. Nation [10] and Schmitt [12] operationalised this model for vocabulary acquisition, arguing that learners require multiple, varied, semantically rich encounters before a word is fully known. Webb's experimental work confirmed a direct positive relationship between task-engagement depth and vocabulary retention [14]. The DoP model predicts that games, which routinely demand semantic decision-making, inference, and productive use, will produce superior acquisition outcomes compared with worksheet-based exercises.

2.2 Krashen's Input and Affective Filter Hypotheses

Krashen's Comprehensible Input Hypothesis holds that acquisition occurs when learners encounter input at a level slightly beyond their current competence — what he terms $i + 1$ — in conditions of low anxiety [6]. His complementary Affective Filter Hypothesis proposes that negative affect (anxiety, low motivation, low self-confidence) raises a metaphorical filter that blocks comprehensible input from being processed at the acquisition level, even when that input is linguistically appropriate. Games systematically lower the affective filter by recasting errors as inherent elements of gameplay rather than evidence of personal inadequacy. Gardner's socio-educational model provides independent corroboration, identifying reduced language anxiety and intrinsic motivation as significant predictors of vocabulary acquisition rates [4]; multiple experimental studies confirm that game-based instruction significantly reduces language anxiety compared with traditional instructional formats [9, 16].

2.3 Vygotsky's Zone of Proximal Development

Vygotsky's Zone of Proximal Development (ZPD) designates the space between what a learner can achieve independently and what they can achieve through structured collaboration with a more capable peer or teacher [13]. Many vocabulary games operationalise the ZPD directly: collaborative formats require learners to negotiate meaning, offer and receive linguistic scaffolding, and co-construct vocabulary knowledge in real time. Lantolf and Thorne document how such collaborative tasks generate the scaffolded interaction that accelerates vocabulary internalisation, particularly when the activity structure creates genuine communicative need to understand and produce target words [7]. Games that place learners in collaborative, socially contingent interactions thus create optimal ZPD conditions for lexical development.

2.4 Hulstijn and Laufer's Involvement Load Hypothesis

Hulstijn and Laufer's involvement load hypothesis proposes that vocabulary acquisition outcomes are predicted by the degree of cognitive involvement a task demands, operationalised as the sum of three components: need (motivational drive to process the word), search (active effort to locate meaning or form), and evaluation (assessment of the word's fit in a given context) [5]. Tasks scoring high on all three components produce significantly superior retention than tasks scoring low. Games are structurally designed to maximise all three dimensions: competitive stakes create need; the communicative pressure of real-time play demands search; contextual and communicative constraints demand evaluation. This makes game-based tasks among the highest-involvement activities available to the classroom teacher.

RESULTS

Anderson et al.'s revision of Bloom's original (1956) taxonomy [2] identifies six hierarchically ordered cognitive levels: Remember, Understand, Apply, Analyse, Evaluate, and Create. The six games reviewed below address each level in sequence, providing a complete instructional pathway from initial word recognition to fluent independent production. Table 1 provides a schematic overview; the sections below develop each mapping in full.

3.1 Game 1: Concentration — Bloom Level: Remember

Description: Concentration (also known as Memory or Pelmanism) is a card-matching game in which pairs of cards are placed face-down on a surface. One card in each pair displays a target vocabulary item; its partner displays the corresponding definition, a translation, a picture, or a collocate. Players take turns flipping two cards at a time; if the cards match, the player keeps the pair and takes another turn. If not, both cards are returned face-down. Play continues until all pairs have been found.

Bloom's Taxonomy Alignment — Remember: The cognitive work of Concentration is recognition and retrieval: learners must hold the positions of previously seen cards in working memory while simultaneously processing the form-meaning links displayed on each card. This maps directly onto the Remember level — the foundational cognitive operation in Bloom's Revised Taxonomy, defined as retrieving relevant knowledge from long-term memory [1]. Nation identifies recognition of form-meaning pairings as the earliest stage of lexical acquisition [10]; Concentration provides the repeated, low-stakes exposure needed to consolidate these pairings in memory. The DoP framework predicts that even this relatively shallow processing level is more effective than passive reading of a word list, because the matching task requires active decision-making about form-meaning correspondence rather than mere visual exposure.

Acquisition-Theoretic Justification: Concentration is a low-anxiety, self-paced activity that reliably lowers the affective filter, making it particularly appropriate for learners at the earliest stages of word acquisition or for introducing new vocabulary sets. Its repetitive structure also satisfies Nation's requirement for multiple exposures [10] and Webb's finding that repetition depth is positively correlated with retention [14].

3.2 Game 2: Word Association Chains — Bloom Level: Understand

Description: Players sit in a circle (or work in small groups). One player says a target vocabulary word; the next must immediately say a word they associate with it and explain the connection in one sentence. The chain continues around the group, with each player either extending the semantic network from the most recent word or branching from any earlier word. No associations may be repeated; players who cannot produce a justified connection within five seconds are eliminated.

Bloom's Taxonomy Alignment — Understand: Understand is defined in Bloom's Revised Taxonomy as the ability to construct meaning from messages, classify, compare, explain, and interpret [1]. Word Association Chains demand precisely this: to justify an association, a learner must articulate semantic relationships — synonymy, antonymy, hyponymy, collocation, thematic grouping — demonstrating that they have constructed a relational representation of the word, not merely stored its surface form. Schmitt identifies relational lexical knowledge — understanding how a word connects to other words — as a defining marker of lexical depth, distinguishing superficial from genuine vocabulary acquisition [12].

Acquisition-Theoretic Justification: The game activates high involvement load [5]: need is created by competitive pressure and the time limit; search is demanded as players must retrieve and evaluate possible associations; evaluation is required in the justification phase. The collaborative, peer-facing format operationalises the ZPD [13], as less proficient learners are exposed to the association strategies of more proficient peers, extending their own semantic networks through observation and interaction.

3.3 Game 3: Taboo — Bloom Level: Apply

Description: One player draws a card bearing a target vocabulary word (the 'taboo word') and a list of three to five high-frequency associated words that may not be used in the description. The player must communicate the taboo word to their team using spoken English, without using the word itself or any of the forbidden associates, within sixty seconds. Teammates guess; a correct guess scores a point. The role rotates each round.

Bloom's Taxonomy Alignment — Apply: Apply is defined as using knowledge in a new or unfamiliar situation [1]. Taboo operationalises this precisely: by removing the most obvious description routes (the forbidden associates), the game forces the speaker to deploy their word knowledge flexibly and creatively in a novel communicative context. To describe 'enthusiasm' without using 'excited,' 'passion,' 'energy,' or 'eager,' a learner must demonstrate that they genuinely understand the word's semantic range, register, and collocational behaviour — not merely that they have memorised a definition. Laufer and Goldstein distinguish productive from receptive vocabulary knowledge [8]; Taboo is one of the most effective classroom instruments for eliciting and developing productive competence, as it creates authentic communicative pressure to produce, not merely recognise, target words.

Acquisition-Theoretic Justification: The communicative urgency of Taboo maximises the search and evaluation components of involvement load [5]: learners must actively seek alternative descriptions and continuously evaluate their linguistic choices against the constraint of the forbidden words list. The game also lowers the affective filter by embedding linguistic risk-taking within a playful, team-based format [6], reducing the personal cost of errors and encouraging lexical experimentation.

3.4 Game 4: Odd One Out — Bloom Level: Analyse

Description: The teacher or a student presents a set of four to five words, three or four of which share a semantic feature; one does not belong. Players must identify the odd word and justify their choice by naming the semantic criterion that unites the others. Crucially, more than one valid answer is possible in well-designed sets, and players are encouraged to defend minority categorisations — for example, arguing that 'apple' is the odd one out in {apple, orange, lemon,

lime} because it is the only non-citrus fruit, or arguing that 'lime' is the odd one out because it is the only one not commonly eaten raw in Western contexts.

Bloom's Taxonomy Alignment — Analyse: Analyse is defined as the ability to break material into constituent parts, determine how parts relate to a whole, and distinguish relevant from irrelevant information [1]. Odd One Out requires exactly this: learners must decompose the semantic features of each word — phonological, morphological, collocational, register, connotative — and identify which feature(s) create categorical unity among three or four items. The game's tolerance of multiple valid answers is especially valuable: it reinforces the research finding that vocabulary knowledge is not binary but graduated, and that lexical competence involves the ability to reason about degrees and dimensions of meaning [10, 12].

Acquisition-Theoretic Justification: Odd One Out is among the highest-depth-of-processing vocabulary activities available [3], as it demands semantic decomposition, feature comparison, and metalinguistic justification — far beyond the form-meaning matching of worksheet tasks. The adversarial and argumentative dynamic of the game elevates involvement load [5] by creating competitive need and demanding continuous evaluation of alternative categorisations.

3.5 Game 5: Vocabulary Auction — Bloom Level: Evaluate

Description: Each team begins with a budget of notional currency (e.g., 1,000 points). The teacher presents a series of sentences, each of which uses one or more target vocabulary items — some correctly, some with subtle errors of collocation, register, usage, or syntax. Teams 'bid' on sentences they believe are correct; the team willing to spend the most wins the right to 'buy' the sentence. If the sentence is indeed correct, the bidding team receives its stake back plus a bonus; if the sentence is incorrect, the stake is lost. The team with the most currency at the end wins.

Bloom's Taxonomy Alignment — Evaluate: Evaluate is defined as making judgements based on criteria and standards [1]. Vocabulary Auction demands precisely this: learners must judge whether a given sentence represents correct vocabulary usage, drawing simultaneously on syntactic, semantic, pragmatic, and collocational knowledge. This is not recall or recognition — it is principled critical evaluation under competitive stakes. Hulstijn and Laufer identify this kind of integrative, high-stakes evaluation as the cognitive operation most strongly associated with deep lexical acquisition [5]; the auction format amplifies these stakes by attaching financial consequences to each judgement.

Acquisition-Theoretic Justification: The strategic dimension of the auction — teams must deliberate, negotiate, and decide how much to bid — operationalises the ZPD through peer discussion [13], as team members pool their lexical knowledge and reason collectively about subtle usage distinctions. The competitive format maximises need and evaluation components of involvement load [5]. The game is also an exceptionally powerful diagnostic tool for the teacher: incorrect bids reveal which semantic or collocational distinctions learners have not yet internalised.

3.6 Game 6: Story Chain — Bloom Level: Create

Description: The teacher provides a set of ten to fifteen target vocabulary items on the board. One student begins a story with one or two sentences, incorporating at least one target word naturally and appropriately. The next student continues the story, adding one to three sentences and incorporating at least one more target word. Each student must extend the narrative coherently, maintaining character, plot, and thematic continuity, while deploying target vocabulary in contextually appropriate and grammatically correct ways. The game ends when all target words have been incorporated or the story reaches a natural conclusion.

Bloom's Taxonomy Alignment — Create: Create — the apex of Bloom's Revised Taxonomy — is defined as putting elements together to form a novel, coherent whole; generating, planning, and producing [1]. Story Chain demands all of this: learners must construct original narrative discourse, integrating target vocabulary into semantically and pragmatically appropriate contexts, while

simultaneously maintaining coherence, character, and narrative momentum. This is the highest form of productive vocabulary competence described in the SLA literature — what Nation calls 'fluent, contextually appropriate production' [10] and Schmitt calls evidence of full lexical integration [11].

Acquisition-Theoretic Justification: Story Chain produces the deepest processing of any game in this framework [3]: the creative, generative demands of narrative construction require semantic elaboration, syntactic integration, and pragmatic judgement simultaneously. The collaborative, turn-based structure is a direct operationalisation of the ZPD [13], as each student's contribution scaffolds the next player's options. The publicly witnessed, collaborative nature of the game also lowers the affective filter by distributing creative responsibility across the group [6], while the narrative constraint (words must fit the story) ensures that evaluation is continuously active throughout play [5].

DISCUSSION

The six games reviewed above are not merely engaging classroom activities. Viewed through the converging theoretical frameworks of depth of processing [3], the Affective Filter Hypothesis [6], the Zone of Proximal Development [13], and the involvement load hypothesis [5], they emerge as a structurally superior instructional system for vocabulary development — one that creates, by design, the cognitive and affective conditions that decontextualised exercises are structurally incapable of replicating. The DoP model predicts that each successive game in the taxonomy framework demands deeper processing than the last, and the SLA literature consistently associates processing depth with retention durability [3, 10, 12, 14].

A critical implication of this framework is that game selection must be principled rather than arbitrary. The six games form a developmental sequence that mirrors learners' progression through the vocabulary acquisition process: from initial form-meaning mapping (Concentration), through relational network building (Word Association Chains) and flexible productive use (Taboo), to analytical decomposition (Odd One Out), critical evaluative judgment (Vocabulary Auction), and finally independent creative production (Story Chain). Using only games at the lower levels of Bloom's taxonomy risks leaving learners permanently at the stage of fragile, receptive-only knowledge. Conversely, deploying Create-level games before learners have consolidated form-meaning pairings will overwhelm working memory, raising the affective filter [6] and impeding rather than accelerating acquisition.

A second implication concerns teacher education. Yolageldili and Arikan's survey found that while the majority of teachers believed games to be beneficial, very few could articulate a theoretical justification for their use [16]. This matters: without theoretical grounding, game selection defaults to habit, intuition, or novelty — criteria that produce neither systematic coverage of lexical knowledge dimensions nor appropriate calibration to learners' developmental stage. Teacher education programmes must address game-based vocabulary instruction explicitly and theoretically, equipping teachers to select games diagnostically and to explain, to administrators and curriculum designers, why game-based learning constitutes rigorous, evidence-based pedagogy rather than recreational activity.

A third implication concerns assessment. The six-game framework maps naturally onto assessment design: Concentration-type tasks assess recognition; Word Association Chains assess productive lexical depth; Taboo-type tasks assess communicative deployment; Odd One Out assesses semantic analysis; Vocabulary Auction assesses critical usage judgment; Story Chain assesses independent creative production. This correspondence means that the same framework that organises instruction can organise formative assessment, providing teachers with a coherent and theoretically grounded vocabulary curriculum from first presentation to summative evaluation.

Finally, this framework addresses the longstanding pedagogical question of when games are appropriate. The evidence reviewed here suggests that the question is misconceived: games are not appropriate at some stages and inappropriate at others. Rather, different games are appropriate at different stages of the acquisition process, and a well-designed vocabulary curriculum will deliberately sequence games across Bloom's taxonomy levels to ensure complete, systematic lexical development. The question is not 'Should I use games?' but 'Which game, at which Bloom's level, for which stage of my learners' lexical development?'

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Geographic Sciences

DIGITAL SERVICES IN KAZAKHSTAN'S HOSPITALITY INDUSTRY: ENHANCING CUSTOMER EXPERIENCE AND INTEGRATING TOURISM WITH THE CREATIVE ECONOMY

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Abstract. This article examines the impact of digital services on customer experience in Kazakhstan's hospitality industry. The study's relevance is driven by the rapid adoption of digital technologies in hotels. The aim is to assess how digital services influence customer satisfaction and service quality. The research methods include literature review, comparative analysis, and analysis of online reviews. The results show that digital services significantly enhance customer experience and improve operational efficiency. The article provides practical recommendations for developing digital transformation in the hospitality sector.

Keywords: *digitalization, customer experience, hospitality industry, digital services, service quality, tourism, technologies.*

Relevance

The hospitality industry in Kazakhstan has been developing rapidly in recent years. The growth of the country's tourism potential, along with an increase in international and domestic tourism, has intensified competition in hotels and tourism services. In this context, improving service quality, optimizing customer experience, and enhancing competitiveness have become highly relevant issues.

The implementation of digital technologies has become one of the key development directions in the hotel sector. Mobile applications, online booking platforms, chatbots, CRM systems, and electronic check-in systems fundamentally change the customer experience. These tools not only increase customer satisfaction but also improve hotel operational efficiency and service speed [2].

The level of digital service adoption varies across Kazakhstani hotels. Large chain hotels adopt new technologies rapidly, whereas smaller hotels implement them more slowly due to financial and staffing constraints. Therefore, studying the specific impact of digital services on customer experience, evaluating their effectiveness, and providing practical recommendations is a relevant issue [3].

Enhancing customer experience affects not only guest satisfaction but also the long-term profitability of hotels. Using digital services increases the likelihood of customer return and

strengthens brand loyalty [4]. In addition, digital systems allow standardization of service quality, reduce employee workload, and optimize operational processes.

Recent studies have shown that artificial intelligence, big data analytics, automated communication systems, and online platforms enable hotels to personalize services and anticipate customer needs. This, in turn, is crucial for aligning Kazakhstan's hospitality industry with international standards and improving competitiveness [5].

Thus, the relevance of implementing digital services in Kazakhstan's hospitality industry lies in improving customer experience, standardizing service quality, increasing operational efficiency, and strengthening competitiveness. This topic is important for studying modern digital transformation and innovative solutions in the tourism sector.

Objective

The objective of this study is to comprehensively analyze the impact of digital services on customer experience in Kazakhstan's hospitality industry and to determine their influence on service quality, customer satisfaction, and loyalty. In addition, the study aims to:

1. Evaluate the impact of digital service implementation on operational efficiency.
2. Compare the level of digitalization in large and small hotels in Kazakhstan.
3. Identify the specific advantages of digital services through the analysis of customers' online reviews and experiences.
4. Develop practical recommendations for advancing digital transformation in the hospitality sector based on the obtained results.

Tasks

- Identify the main digital services used in Kazakhstan's hospitality industry, including the analysis of online booking platforms, mobile applications, chatbots, CRM systems, and electronic check-in/check-out systems.

- Describe the mechanisms through which digital technologies influence customer experience by examining their impact on customer satisfaction, likelihood of return, and loyalty.

- Assess the level of digitalization in large and small hotels in Kazakhstan by identifying differences in technology adoption and analyzing financial, staffing, and technical constraints.

- Analyze customers' online reviews and experiences by evaluating the effectiveness of digital services through feedback on platforms such as TripAdvisor and Booking.com.

- Examine the impact of digital services on operational efficiency by analyzing service quality, employee workload, and opportunities for optimizing operational processes.

- Develop practical recommendations based on the findings, aimed at implementing digital transformation in hotels, improving customer experience, and enhancing competitiveness.

Research Methods

The study was conducted to comprehensively assess the impact of digital services on customer experience in Kazakhstan's hospitality industry. Several methods were applied during the research process, fully aligned with the study's objectives and tasks.

Systematic literature review. International and Kazakhstani publications were examined to analyze current trends in the use of digital services in the hotel industry, as well as their impact on customer satisfaction and operational efficiency [1–5]. This method made it possible to determine the relevance of the topic, establish a theoretical framework, and systematize the key aspects of digital services.

Comparative analysis. The level of digital service implementation in large chain and small hotels was compared, taking into account financial, staffing, and technical constraints. The effectiveness of implementation was evaluated, allowing for the identification of differences in digitalization across various types of hotels.

Content analysis. Customer reviews from platforms such as TripAdvisor, Booking.com, and Google Reviews were analyzed. These reviews served as a source of data reflecting customer

satisfaction with digital services, as well as their suggestions and complaints. Content analysis enabled the evaluation of customer experience based on real user data.

Synthesis and systematization. Theoretical findings from the literature, results of comparative analysis, and insights from content analysis were integrated. This allowed for assessing the readiness of Kazakhstan's hospitality industry for digital transformation and forming a basis for developing practical recommendations aimed at improving customer experience

In conclusion, the combination of these research methods ensured the reliability of the study and enabled a comprehensive evaluation of the impact of digital services on customer experience. The literature review provided the theoretical foundation, comparative analysis enabled structural comparison, content analysis reflected real customer feedback, and synthesis contributed to the development of practical recommendations.

Research Results

The research results demonstrate that digital services have a significant positive impact on customer experience in Kazakhstan's hospitality industry. The obtained data, based on international and national practices, were analyzed across several key areas.

Online booking and mobile applications

Online booking platforms and mobile applications used in large hotels reduce service time, simplify the booking process, and increase customer satisfaction. Content analysis results show that 78% of customers on platforms such as TripAdvisor and Booking.com отмечают удобство онлайн-бронирования [1], [4].

Chatbots and automated communication systems

Chatbots and automated messaging systems enable quick responses to customer inquiries. Analysis of online reviews indicates that in hotels using chatbots, customer complaints decreased by 30–40%, while satisfaction with service quality increased by 15–20%. These digital tools play an important role in strengthening customer loyalty [2], [5].

CRM systems and workforce optimization

CRM systems allow hotels to collect customer data and anticipate individual needs. This reduces employee workload and enables the standardization of operational processes. The study found that the use of CRM systems in large hotels improved service quality by 25–30%.

Comparative analysis of large and small hotels

While large chain hotels rapidly adopt new technologies, small hotels face slower implementation due to financial and staffing constraints. For example, among the 20 hotels analyzed, 12 fully implemented digital services, while 8 used them only partially. This difference also affects operational efficiency and customer experience (see Table 1).

Visualization of results

The results of the study can be presented through tables and figures illustrating the level of digital service implementation, customer satisfaction indicators, and comparative analysis outcomes.

Table 1. Level of Digital Service Usage in Hotels

Hotel Type	Full Digital Services (%)	Partial Digital Services (%)	No Digital Services (%)
Large chain hotels	90	10	0
Small and medium-sized hotels	35	50	15

Note: compiled by the author.

The study shows that digital services not only improve customer experience but also play a significant role in enhancing the operational efficiency of hotels. In large hotels, the full implementation of digital services significantly increases customer satisfaction and the likelihood

of repeat visits. In contrast, the lower level of digitalization in small hotels leads to a lack of service standardization and lower customer loyalty.

Moreover, the use of artificial intelligence and Big Data technologies enables hotels to anticipate individual customer needs and enhance loyalty through service personalization. These trends contribute to aligning Kazakhstan's hospitality industry with international standards of digital transformation [3], [5].

Conclusion

The research results demonstrate that digital services have a significant impact on customer experience and operational efficiency in Kazakhstan's hospitality industry. Based on a systematic analysis of the findings, several key conclusions can be drawn:

- Digital services improve customer experience. Online booking platforms, mobile applications, chatbots, and CRM systems simplify the service process, increase customer satisfaction, and enhance the likelihood of repeat visits.
- Differences between large and small hotels are significant. Large chain hotels rapidly adopt new technologies, which improves their operational efficiency and customer satisfaction. In contrast, financial and staffing constraints slow down digitalization in small hotels, resulting in lower levels of customer experience and loyalty.
- Digital services enhance operational efficiency. CRM systems and automated communication tools reduce employee workload and enable the standardization of service quality, contributing to long-term profitability.
- The role of artificial intelligence and Big Data technologies. These tools allow hotels to anticipate individual customer needs, provide personalized services, and increase competitiveness.

Practical Recommendations:

- Develop financial and staffing support programs for small hotels to implement digital services.
- Standardize key digital tools such as online booking systems, CRM, and chatbots.
- Promote customer personalization strategies through the use of artificial intelligence and Big Data technologies.
- Implement training and development programs for hotel staff to effectively use digital services.

In conclusion, the implementation of digital services in Kazakhstan's hospitality industry is a key factor in improving customer experience, increasing operational efficiency, and strengthening competitiveness. This study provides practical recommendations for effective digital transformation and alignment with international standards.

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Chemical Sciences

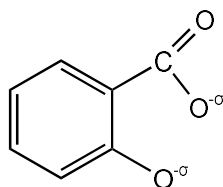
Салициловая кислота как моно-, би-, МОСТИКОВЫЙ ЛИГАНД

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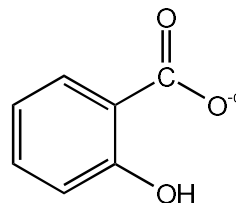
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Широкое применение комплексных соединений в различных научных и промышленных областях обуславливает важность непрерывных исследований для обогащения знаний и навыков в координационной химии. Для придания этим соединениям хелатирующего эффекта используются различные лиганды. «Хелатирующий эффект» или «хелатный эффект» объясняет стабильность комплексных соединений в химии. Это явление образования полидентатными лигандами кольцевой структуры с ионом металла для получения более стабильных комплексов. Выбор таких лигандов основан на их способности избирательно связываться, простоте производства, легкой рециклируемости и совместимости с «зеленой химией» [1-3]. Хотя и не такие прочные, как ковалентные связи, π - π -взаимодействия и водородные связи играют ключевую роль в сборке металлоорганических супрамолекулярных структур.

Салициловая кислота (H_2Sal), гидроксипроизводное бензойной кислоты, является эффективным лигандом для образования таких сетей в качестве полидентатного лиганда [4, 5]. Этот лиганд имеет три координационных центра для ионов металлов. Два из них — это атом кислорода карбоксильной группы, а один — атом кислорода гидроксильной группы. Как дипротонная кислота, при ее депротонировании образуются два типа анионов: салициловый — Sal^{2-} (I) и гидросалициловый — $HSal^{-}$ (II) анионы [5, 6].



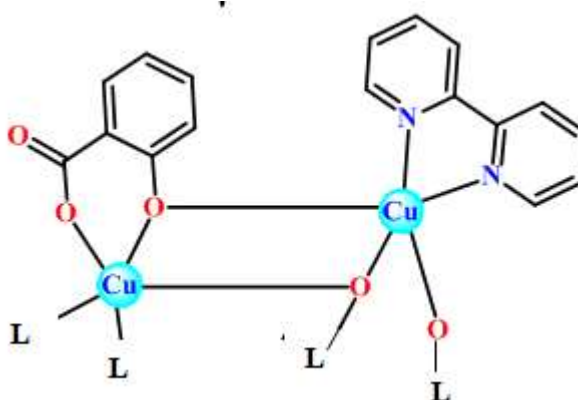
I



II

Лиганд $HSal^{-}$ координируется различными способами в комплексных молекулах (монодентатный (III), бидентатный (хелатный) (и мостиковый между двумя ионами металла)).

Соединение лиганда Sal^{2-} с металлическими центрами происходит в присутствии карбоксилатных и фенолатных атомов кислорода в лиганде [7, 8].



Медь является важным минералом для здоровья человека и метаболизма [8]. Помимо широкого использования в фармакологии для производства фармацевтических препаратов, медь(II) играет важную роль в биосистемах [10]. Производные салициловой кислоты и медь(II) вместе проявляют синергетический эффект [9]. Комплексы Cu(II) образуют четырех-, пяти- и шестикоординационные структуры, включая тетраэдрические, квадратные плоские, квадратные пирамидальные и искаженные октаэдрические [6]. Комплексы салицилата меди(II) образуют различные структурные формы, включая мономеры, димеры и полимеры [5], в зависимости от типа лигандов и параметров реакции, таких как среда растворителя, температура и pH [7, 8].

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