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CONTENT

ARTS

Papanyan N.

SOME STYLISTIC FEATURES OF TIGRAN MANSURIAN'S
MUSICAL LANGUAGE4

Papanyan N.

MASTERY OF NEW MUSICAL TECHNOLOGIES AS AN
IMPORTANT CONDITION FOR THE PREPARATION OF A
MUSIC TEACHER.....7

Urazayeva L.

DECORATIVE PLASTER FINISHES AS MORPHOLOGICAL
AND SEMIOTIC AGENTS IN THE ARTICULATION OF
SPACE11

BIOLOGICAL SCIENCES

Aliyeva M.

PLANT INDICATORS FOR ASSESSING THE ECOLOGICAL
STATE OF FOREST ECOSYSTEMS IN THE TALYSH-
LANKARAN REGION OF AZERBAIJAN.....15

CULTURAL SCIENCES

Archimandrite Abo (Levan Chachua)

THE FUNCTIONING OF THE GEORGIAN ORTHODOX
APOSTOLIC CHURCH IN THE DIASPORA AND THE
ESTABLISHMENT OF GEORGIAN EPARCHIES
ABROAD18

ECONOMIC SCIENCES

Zeynalova S., Karimov K., Sadiqova A.

STRATEGIC DIRECTIONS FOR THE SUSTAINABLE
DEVELOPMENT OF AZERBAIJAN'S INDUSTRIAL
SECTORS21

MATHEMATICAL SCIENCES

Milyute E., Milyus A.

ON THE GEOMETRY OF DEVELOPABLE SURFACES IN
STRATIFIED INCOMING VORTICAL FLOW OVER A
CONE26

MEDICAL SCIENCES

Shkiryak A., Khanenko S.

THE INFLUENCE OF VITAMIN D STATUS ON
COGNITIVE ABILITY IN PATIENTS WITH BIPOLAR
DISORDER AND HEALTHY CONTROLS.....33

Shkiryak A., Khanenko S.

VITAMIN D AND THE RISK OF DEMENTIA AND
ALZHEIMER DISEASE.....43

PEDAGOGICAL SCIENCES

Liao XiaoDong, Kosherbayeva A.,

Kalimoldayeva A.

INNOVATION AND PRACTICE OF EDUCATIONAL
METHODS IN PRIMARY AND SECONDARY SCHOOLS —
FROM THE PERSPECTIVE OF STUDENTS' EMOTIONAL
MANAGEMENT.....52

POLITICAL SCIENCES

Abu Shawer Omar Ahmad

FROM ENERGY CORRIDORS TO DIGITAL CORRIDORS:
PROSPECTS FOR KAZAKHSTAN–GCC COOPERATION IN
AI GOVERNANCE AND DATA INFRASTRUCTURE 57

PSYCHOLOGICAL SCIENCES

Mirzəyeva S., Mustafazadə D.

THE IMPACT OF EDUCATIONAL STRESS ON LEARNING
OUTCOMES IN ADOLESCENTS 59

Quliyeva Ş., Abdullayeva A.

PSYCHOLOGICAL ASPECTS OF THE IMPACT OF
BULLYING ON ADOLESCENT SELF-ESTEEM 65

Hacıyeva A., Rzayeva S.

EXPERIMENTAL STUDY OF STUDENT STRESS LEVELS
DURING THE EDUCATIONAL PROCESS 68

TECHNICAL SCIENCES

Retivykh A., Retivykh V., Marinov A.

COMPARATIVE ANALYSIS OF THE APPLICATION OF
FAST FOURIER TRANSFORM AND NUMBER-
THEORETICAL TRANSFORM IN FULL
HOMOMORPHOUS ENCRYPTION SCHEMES 73

Pantskhava E., Jishkariani M.

THE IMPACT OF ARAB INVESTMENTS ON GEORGIA'S
ENERGY SECTOR: ENERGY AND SOCIO-ECONOMIC
ASPECTS 77

Mammadli S.

ASSESSMENT OF POTENTIAL LIQUID PHASE
FORMATION IN NATURAL GAS PIPELINES 80

Ovcharuk V.

DEVELOPMENT OF THE INFORMATION SYSTEM OF
CONTROL OF QUALITY OF THE INDUSTRIAL
GOODS 85

ARTS

SOME STYLISTIC FEATURES OF TIGRAN MANSURIAN'S MUSICAL LANGUAGE

Papanyan N.

Vanadzor state university named after H. Tumanyan,
Faculty of Social Sciences,
Department of Art and Sports, Lecturer, Armenia

НЕКОТОРЫЕ СТИЛИСТИЧЕСКИЕ ОСОБЕННОСТИ МУЗЫКАЛЬНОГО ЯЗЫКА
ТИГРНА МАНСУРЯНА

Папанян Н.А.

Преподаватель, факультет общественных наук, кафедра искусства и спорта Ванадзорский государственный университет имени О. Туманяна, Армения
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Abstract

This article examines the characteristics of the individual style of Tigran Mansurian, one of the most prominent Armenian composers of the second half of the 20th century and the early 21st century. It analyzes the origins of his artistic thinking, the specifics of his rhythm, timbral dramaturgy, intonational and modal organization, as well as the synthesis of national tradition with contemporary compositional language.

Аннотация

В статье рассматриваются особенности индивидуального стиля Тиграна Мансуряна – одного из наиболее значительных армянских композиторов второй половины XX - начала XXI века. Анализируются истоки его художественного мышления, специфика ритмики, тембровой драматургии, интонационно-ладовой организации, а также синтез национальной традиции и современного композиторского языка.

Keywords: style, monody, neoclassicism, chamber music, vocal lyricism, timbral dramaturgy.

Ключевые слова: стиль, монодия, неоклассицизм, камерная музыка, вокальная лирика, тембровая драматургия.

Введение. Творчество Т. Мансуряна занимает особое место в истории армянской и мировой музыки. Сформировавшись в эпоху активных поисков новых выразительных средств, композитор сумел выработать глубоко индивидуальный стиль, сочетающий аскетизм музыкальной ткани, философскую сосредоточенность и органичную связь с национальной интонационной традицией. Его музыка отличается внутренней тишиной, камерностью высказывания и высокой степенью духовной концентрации.

Материалы и методы. Т. Мансурян принадлежит к поколению композиторов 1960-х годов, чье творчество развивалось в диалоге с европейским музыкальным авангардом. Однако, в отличие от многих современников, он избрал путь не радикального эксперимента, а глубокого осмысления традиции — как западноевропейской, так и армянской. В своем творчестве композитор стремится к лаконизму и внутренней сосредоточенности, опираясь на национальную интонационную память. Исследователи отмечают, что композитор вырабатывает «аскетический модернизм», где новаторство проявляется не в разрушении традиции, а в её глубоким переосмыслении [1].

Существенное влияние на формирование его художественного мировоззрения оказали:

- древнеармянская духовная музыка (шараканы),
- монодическая культура народной песни,

- эстетика минимализма и постсерийного письма,

- традиции европейской полифонии.

При этом композитор избегает прямых цитат, предпочитая тонкую стилизацию и внутреннее переосмысление интонационного материала.

Одной из центральных черт стиля Т. Мансуряна является опора на армянскую монодию. Его мелодика часто строится на интонациях, близких к народной и духовной традиции, но переработанных в условиях современного гармонического мышления.

Характерные особенности:

- использование модальных структур;
- преобладание диатоники с тонкими хроматическими отклонениями;
- отсутствие функциональной гармонической логики в классическом понимании;
- особая роль интервальной выразительности (секунды, кварты, квинты).

Гармония в его сочинениях носит колористический характер и часто строится на созвучиях с открытой структурой, создающих ощущение пространственности и внутренней тишины, что наиболее присуще мышлению французских импрессионистов.

Ритмическая организация музыки Т. Мансуряна отличается свободой и гибкостью. В отличие от ярко выраженной моторики многих композито-

ров XX века, у него доминирует замедленное, созерцательное течение времени. В музыке Т. Мансуряна ощущается влияние драматургии ритма А. Хачатуряна, он также использует асимметричные метрические структуры, протяжённые длительности, паузы, как средство выражения «растянутого времени». У Т. Мансуряна чувство музыкального времени приобретает философский характер, так как не столько развивается, сколько раскрывается постепенно. Такой подход к ритмической выразительности можем наблюдать в музыке А. Тертеряна, А. Шнитке и других.

Очень своеобразна и тембровая драматургия композитора, он отдаёт предпочтение камерным составам, прозрачной фактуре, тонкой динамической градации, при этом используя минимализм фактурных средств, прозрачность звуковой ткани, акустическое послезвучие, выразительность сольных инструментальных линий.

Сонорность, присущая современной музыке выражается в тембровой изобретательности, особенно в камерных и хоровых произведениях, даже в музыке к кинофильмам, где тембр становится носителем эмоционального и философского содержания.

Музыка Т. Мансуряна пронизана внутренней духовностью. Даже в светских сочинениях ощущается сосредоточенность, близкая к молитвенному состоянию. Это проявляется в статичности музыкального развития, в тяготении к медитативным формам, в сдержанности динамики и в особой интонационной чистоте. Он одним из первых армянских композиторов обратился к старинному пласту средневековой поэзии – айренам¹. В его поздних сочинениях усиливается религиозно-философская направленность, обращение к вечным темам памяти, времени, утраты.

Одной из важнейших особенностей стиля Мансуряна является органичный синтез армянской интонационной традиции и европейской композиторской техники XX века. Его музыка глубоко национальна по духу, но универсальна по художественному языку. Композитор создаёт не фольк-

лорные стилизации, а современную музыку, в которой национальный элемент существует как внутренняя интонационная основа.

Рассмотрим стилевые особенности композитора на примере некоторых произведений. Одним из центральных духовных сочинений композитора является «Реквием», посвящённый памяти жертв Геноцида армян. Произведение демонстрирует зрелую форму стилизованного синтеза, где сочетаются латинский канонический текст и армянская интонационная основа, преобладание модальности², строгая, сдержанная динамика, отсутствие внешней трагедийности /драматизм достигается внутренним напряжением/. Фактура преимущественно гомофонно-полифоническая, с частыми имитационными проведением. Музыкальное развитие строится на длительных звуковых пластах, создающих ощущение внеисторического времени, своеобразное противопоставление «единства вечного и бытового начала». «Реквием» демонстрирует духовную глубину стиля Мансуряна, где трагическое выражается через тишину и внутреннюю сосредоточенность.

Из оркестровых произведений выделяется симфоническая четырёхчастная «Партита»³ (Прелюдия, Пастораль, Интермеццо, Токката), где проявились духовная зрелость композитора, рациональность мышления и его полифоническое мастерство. Музыкальный материал «Партиты» развивается посредством ритмических и мелодических формул. Произведение отличается богатой и красочной инструментальной окраской. В линейной мелодии отчётливо просматриваются тонические опорные пункты. Можно говорить о полифонически-линейном переосмыслении гармонически-аккордовой фактуры, что придаёт музыкальному языку черты политональности.

В многообразии художественных явлений и новаторских тенденций искусства XX века возрождаются эстетические принципы музыкальной культуры XVII–XVIII столетий. Для Т. Мансуряна неоклассицизм⁴ стал одним из наиболее излюбленных направлений музыкального мышления начала века. Проведем сравнительный анализ аналогичных жанров у Баха и Т. Мансуряна. Партита у И.

¹ **Айрен** — это средневековая армянская лирическая строфа (стихотворная форма), широко распространённая в армянской поэзии XIII–XVII вв. Слово происходит от армянского «հայրենի» — «родной», «отечественный». Основная тематика: любовь (земная и духовная), философские размышления, нравственные поучения, сатирические мотивы, разлука, судьба, бренность жизни. Традиция айренов связана с творчеством Н. Кучака, Х. Кечареци.

² В армянской духовной и народной традиции модальная основа тесно связана с системой **октоиха** (восьмигласия) и древних ладов шараканной традиции. Модальность основана на ладовом центре, нет строгой доминантовой функции, мышление мелодическое.

³ **Партита** (итал. *partita* — состоящая из частей) — инструментальная пьеса или часть вариационного цикла, получившая широкое распространение в XVI–XVII веках. Нередко вариационный цикл в целом назывался *партитой*. В более поздний период партита стала разновидностью жанра сюиты. В этом жанре сочиняли Джироламо

Фрескобальди, Иоганн Себастьян Бах, а в XX веке — Альфредо Казелла и Луиджи Даллапиккола

⁴ **Неоклассицизм** — направление, сформировавшееся в первой половине XX века. Его основу составляли эстетические принципы XVII–XVIII столетий: обращение к эстетике барокко и раннего классицизма, противопоставление музыке романтизма. В музыке особое значение приобрели чёткие формы, сдержанная выразительность, преобладание диатоники, рационально организованная ритмика, идеи и формы, обновляющие музыкальный язык. Элементы эстетики неоклассицизма можно обнаружить у Клод Дебюсси и Морис Равель. Музыкально-эстетические принципы направления особенно отчётливо проявились в творчестве Игоря Стравинский, Пауль Хиндемит, Альбер Руссель, Дариус Мийо, а также, отчасти, у Отторино Респиги, Сергей Прокофьев и Дмитрий Шостакович.

Баха — это синтез танца, полифонии и архитектурной ясности. Партита у Т. Мансуряна — это современный философский диалог с традицией, в котором жанр освобождается от танцевальности и становится пространством интонационной концентрации. Оба композитора, несмотря на эпохальные различия, сходятся в одном — в стремлении к духовной концентрации:

- у И. Баха — теоцентрическая барочная символика.
- у Т. Мансуряна — экзистенциальная, аскетическая сосредоточенность, близкая к восточно-христианской традиции
- И. Бах — «архитектор времени»: чёткая метрическая пульсация, пропорциональность разделов.
- Т. Мансурян — «поэт времени»: время растягивается, дробится, насыщается паузами; возникает эффект внутренней тишины.

В камерной сфере особенно показателен **Третий струнный квартет**. Здесь проявляется:

- лаконизм тематического материала;
- тончайшая динамическая градация;
- преобладание интервального изложения (секундовые и квартовые структуры).

Форма произведения основана на принципе постепенного сгущения и разрежения звуковой ткани. Музыкальная драматургия строится не на тематическом конфликте, а на изменении звуковой плотности и тембрового баланса. Особое значение имеет тишина — паузы выполняют структурообразующую функцию.

В ряде камерных произведений (сонаты, ансамблевые пьесы) прослеживается типичный для композитора приём:

- выделение сольной линии как «голоса»;
- поддержка её статичными гармоническими пластами;
- постепенное растворение звучания в тишине.

Эти сочинения демонстрируют стремление к предельной концентрации музыкальной мысли и отказу от избыточной фактурной насыщенности.

Особое место в творчестве композитора занимает вокальная лирика как диалог со словом. Следует отметить глубокое благоговение композитора перед армянским языком и, шире, перед словом вообще, что проявляется во всех его вокальных произведениях. Даже тогда, когда отдельно взятая мелодическая линия не обнаруживает внутренних связей с интонационными оборотами национальной музыки, его сочинения всё равно продолжают звучать «по-армянски» — прежде всего благодаря предельно точной акцентуации, вытекающей из особенностей армянского языка, а затем — благодаря глубокому раскрытию генетического подтекста. Это было особенно значительным явлением в армянской вокальной музыке середины XX века, где нередко происходило прямо противоположное: очевидное стремление к подчеркнутой «армянско-

сти» приводило к принципиальной несовместимости речи и пения. Первая из вокальных циклов Т. Мансуряна — «Четыре стихотворения Лорки» — единственная, где использован переводной текст, а потому и единственная, в которой точности акцентуации отведена сравнительно более скромная роль по сравнению с раскрытием образа. Следующий вокальный цикл — «4 айрена» на стихи средневекового поэта Наапета Кучака — относится к числу самых известных произведений Т. Мансуряна. Поэтому, избегая собственно музыкального анализа, попробуем ограничиться выявлением внутренних связей между звуком и текстом. Прежде всего обращает на себя внимание то, что здесь меняется направленность текста. В «Айренах» исчезает «ты» как действующее лицо, превращаясь в неосуществлённое, недостижимое желание. Музыка словно интерпретирует недостижимость этого «ты» через интонационные миры, заимствованные из армянского церковного пения. Пуантилистическое дробление отдельных мелодических оборотов становится символом внутренней боли, и по мере нарастания драматического напряжения расширяется регистровый разрыв между звуками мелодии.

В музыке к кинофильмам сохраняются его характерные черты — интонационная аскеза, тонкая тембровая работа и духовная сосредоточенность. Однако жанровые задачи определяют различие выразительных средств. Т. Мансурян — автор музыки к фильмам выдающихся режиссёров, прежде всего Сергей Параджанов — «Цвет граната», где в лаконичной форме создаёт символический образ в своеобразном звуковом пространстве. Музыка не сопровождает действие, а формирует особую духовную атмосферу кадра, а тембровая символика воспринимается как часть визуального мышления.

Заключение. Стиль Тиграна Т. Мансуряна характеризуется аскетизмом выразительных средств, модальной интонационной основой, особым типом временной организации и духовной направленностью. Его музыка представляет собой философское осмысление звука, в котором тишина и пауза становятся равноправными элементами формы.

Композитор создал художественную модель, соединяющую национальную идентичность и универсальный современный язык, что позволяет рассматривать его творчество как значительный вклад в мировую музыкальную культуру конца XX — начала XXI века.

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MASTERY OF NEW MUSICAL TECHNOLOGIES AS AN IMPORTANT CONDITION FOR THE PREPARATION OF A MUSIC TEACHER**Papanyan N.**

*Vanadzor state university named after H.Tumanyan,
Faculty of Social Sciences,
Department of Art and Sports, Lecturer, Armenia*

ВЛАДЕНИЕ НОВЫМИ МУЗЫКАЛЬНЫМИ ТЕХНОЛОГИЯМИ КАК ВАЖНОЕ УСЛОВИЕ ПОДГОТОВКИ УЧИТЕЛЯ МУЗЫКИ**Папанян Н.А.**

Преподаватель, факультет общественных наук, кафедра искусства и спорта Ванадзорский государственный университет имени О. Туманяна, Армения
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Abstract

The purpose of this work is to identify the specific features of the music teacher's profession and to determine which new technologies can be applied in music lessons. The study reveals the characteristics of musical-pedagogical activity, including areas of theoretical, musicological, and pedagogical knowledge, as well as conducting and performing skills. The necessity of an in-depth knowledge of the methodology of musical education and teaching in school is substantiated. In order for music education to become truly developmental, it is necessary to ensure that students' activities in music classes are carried out as artistic in content and educational in form.

Аннотация

Целью данной работы является выявление особенностей профессии учителя музыки, а также определение того, какие новые технологии могут применяться на уроках музыки. Выявлены особенности музыкально-педагогической деятельности, области теоретических, музыковедческих, педагогических знаний, дирижерских и исполнительских умений. Обоснована необходимость углубленного знания методики музыкального воспитания и преподавания в школе, чтобы музыкальное образование стало действительно развивающим, надо добиваться, чтобы деятельность школьников на уроках музыкального искусства осуществлялась как художественная по содержанию и учебная по форме.

Keywords: methodology, education, pedagogy, solfeggio, harmony, analysis, texture, mode, rhythm.

Ключевые слова: методика, образование, педагогика, сольфеджио, гармония, анализ, фактура, лад, ритм.

Введение. Изучение искусства в процессе школьного обучения имеет свои особенности, связанные со спецификой человеческого мышления, восприятия, познания, воображения и эмоционального мира. Их формирование, совершенствование и развитие способствуют более полноценному познанию и осмыслению жизни и окружающей сложной действительности, что обогащает, наполняет смыслом и делает более целенаправленной жизнь человека.

Профессия учителя музыки требует, чтобы профессиональные знания, навыки и умения сочетались с педагогическими умениями и навыками. Следует отметить, что учитель музыки не всегда воспринимает свою профессию комплексно, иногда проявляя себя лишь в одном виде музыкально-педагогической деятельности и имея недостатки в другом (например, хорошо знает историю музыки, но слабо — теорию; владеет дирижерским аппаратом, но плохо владеет инструментом и т.д.). Современная образовательная система предъявляет к учителю требование быть всесторонне образованным.

Целью данной работы является выявление особенностей профессии учителя музыки, а также определение того, какие новые технологии могут

применяться на уроках музыки. Данная цель конкретизируется решением следующих задач:

1. раскрытие творческого характера деятельности учителя музыки;
2. выявление знаний, умений и навыков, необходимых учителю музыки, работающему в школе;
3. выявление музыкальных технологий.

Практика показывает, что только специалист, обладающий комплексными знаниями, умениями и навыками в различных областях музыкально-педагогической деятельности, способен проводить качественный урок музыки.

Урок музыки — это урок искусства. Следовательно, логика организации урока, применяемые методы, взаимоотношения между учителем и учениками подчиняются музыкальным закономерностям. Урок музыки имеет свою динамику, кульминацию и завершение. Драматургия урока подобна музыкальным формам (она может быть трёхчастной, иметь структуру рондо или вариаций). В целом урок музыки по своему содержанию и форме представляет собой своего рода «произведение искусства». Во время уроков должна звучать музыка, которая будет способствовать формированию у учащихся здоровых музыкальных потребностей и

развитию вкуса. На уроке музыки тесно взаимодействуют мысли и чувства, а творческие стремления учителя и учеников совпадают.

Творческая активность учащихся, их инициативность, свобода ответов и суждений, а также чувство удовлетворения являются характерными особенностями урока музыки.

Материалы и методы. Разрабатывая план урока музыки, следует помнить, что его идея зависит не только от программы предмета и педагогической задачи, но и от времени, отведённого на усвоение программного материала. Замысел урока должен соответствовать требованиям современной жизни и восприятию эпохи. При подготовке к уроку необходимо учитывать, что замысел должен быть интересным, а уже знакомый, достаточно усвоенный материал следует раскрывать по-новому. Творческий замысел учителя прежде всего должен реализовываться посредством правильного выбора методических средств освоения произведения. Необходимо уметь подбирать соответствующие вокальные упражнения для подготовки к изучению данного хорового произведения, искать различные варианты интерпретации произведения, отходить от застывших, шаблонных построений урока. Учитель музыки должен ставить перед собой задачу постоянно изменять и совершенствовать свои подходы, искать новые, ранее не использованные формы, чтобы организовать музыкальную деятельность учащихся и вызвать у них интерес.

Создавая драматургию урока, учитель должен уметь формировать чувство педагогического времени. В соответствии с ритмом урока учитель-музыкант выбирает темп и ритм своей речи, организует и другие средства педагогического воздействия. Таким образом, концепция урока должна включать следующие компоненты:

- художественную, воспитательную и эстетическую сверхзадачу;
- психологию музыкально-образовательного процесса — его эмоционально-познавательные возможности;
- возможности для творческой и исполнительской деятельности учащихся.

Музыкально-педагогическая деятельность объединяет педагогическую, дирижёрскую, музыковедческую, исполнительскую и научно-исследовательскую работу, основанную на способности самостоятельно обобщать и систематизировать полученные знания. Творческая деятельность учителя обусловлена особенностями его работы, которая осуществляется перед определённой аудиторией и требует умения управлять собственными эмоциями и чувствами. Педагогическая деятельность является непрерывным творческим процессом. На уроке музыки она приобретает двусторонний характер: с одной стороны — творческая деятельность учителя, с другой — на основе стимулирующих методов, применяемых учителем, развивается творческая деятельность учащихся. Творческое состояние класса необходимо стимулировать и превращать творческий поиск в коллективный процесс, пробуждая творческое воображение.

Творческая деятельность учителя требует способности к импровизации, умения действовать экспромтом, что позволяет правильно оценивать ситуацию и быстро ориентироваться при решении педагогических задач. В этом огромную роль играют педагогико-психологическая грамотность и эрудиция учителя. Музыкальное искусство по своей природе открывает перед учителем широкие творческие возможности. Это проявляется не только в осознании произведения, но и в его интерпретации, которая основывается на раскрытии замысла композитора, идеи, художественного образа и содержания произведения. В этом решающую роль играют музыкально-слуховые представления музыканта, его интеллект, музыкальный опыт и владение выразительными средствами.

Следует отметить, что творческая деятельность в области искусства требует от человека высокой эмоциональности, образного мышления и богатой художественной восприимчивости. Деятельность учителя музыки зависит от нескольких факторов: условий работы, общего уровня класса, музыкальной подготовки учащихся и личных качеств самого учителя. Чтобы творческие проявления учащихся носили устойчивый и активный характер, учителю необходимо как на уроках музыки, так и во внеурочной работе подбирать такие произведения, которые могут служить основой для развития творческих способностей и одновременно соответствовать решению общих дидактических задач. Поскольку «Музыка» является школьным предметом, она должна преподаваться так же, как и другие дисциплины школьной программы. Однако среди школьных предметов «Музыка» имеет свои особенности, так как является уроком искусства и входит в цикл эстетических дисциплин. При таком подходе цели, содержание и методы музыкального образования подчиняются главной задаче — обеспечить формирование знаний, умений и навыков различного уровня, достаточно чётко определённых для каждого возрастного этапа обучения.

Основой такой образовательной модели преподавания музыки стала система профессионального музыкального образования, что является естественным и логичным. Однако в массовом музыкальном образовании, с одной стороны, отсутствует такой важный компонент, как обучение игре на музыкальном инструменте, а с другой стороны, небольшое количество учебного времени и преимущественно коллективная форма обучения делают её упрощённым и сокращённым вариантом профессионального музыкального образования. Сам учитель становится своего рода универсалом: в течение одного урока он должен успеть обучить детей музыкальной грамоте, сформировать навыки слушания музыки, осуществлять ритмическое воспитание, дать сведения о произведении и его авторе, разучить с детьми песенный репертуар, проанализировать выразительные средства произведения и т.д.

Учитель музыки общеобразовательной школы учит учащихся управлять своим восприятием в процессе музыкального познания. Иначе говоря, он

учит слушать «и умом, и сердцем». Для успешной деятельности учителя музыки большое значение имеют педагогические способности. В профессиональной характеристике учителя важное место занимают индивидуальные особенности, соответствующие его интересам, стремлениям, потребностям и чертам характера. В процессе профессиональной деятельности врождённые качества человека постепенно изменяются, и более ярко проявляются те черты, которые необходимы для данной профессии.

Формирование музыкальных способностей подчиняется общим закономерностям развития способностей. Б. Теплов, исследуя структуру музыкальных способностей, отметил, что они подчиняются общим закономерностям развития. Именно он впервые ввёл понятие «музыкальности» как системного проявления музыкальной одарённости и определил её основные компоненты: эмоционально-эстетическое отношение к окружающему миру, образное мышление, систему музыкально-слуховых представлений, включающую различные качественные характеристики музыкального слуха, а также ладовое и ритмическое чувство⁵.

В образе учителя музыки особое место должно занимать мышление, которое лежит в основе его профессиональной деятельности. В процессе исполнения и восприятия музыкального произведения ощущения возникают прежде всего под воздействием реально звучащей музыки или музыки, воспринимаемой внутренним слухом, что порождает музыкальные образы. Ощущение характера и качества звучания, тембра и динамики позволяет музыканту находить необходимые выразительные средства, достигать требуемого звучания и передавать художественный образ, рождающийся в воображении.

Музыкальное мышление является особым видом общечеловеческого мышления. Закономерности мышления в музыкальной реальности приобретают специфический характер, поскольку отражение действительности происходит через обобщённые музыкальные образы. В основе музыкального мышления лежит слуховая деятельность, представляющая собой взаимосвязанную систему музыкально-двигательных и зрительных представлений. Б. Теплов подчёркивал огромную роль музыкально-слуховых представлений для любой формы музыкальной деятельности, поскольку они содержат логику построения музыкального произведения, его форму и структуру, способствуют чувственному восприятию и проникновению в художественный образ, лежащий в основе произведения.

Накопление музыкально-слуховых представлений происходит на основе музыкального опыта. Только музыкант-педагог, обладающий хорошо развитым музыкальным слухом и способностями (ладовыми, звуковысотными, гармоническими, тембровыми, динамическими, ритмическими, музыкальной памятью), тонкой эмоциональной чувствительностью и воображением, может развивать

музыкальные способности у других и проводить урок на высоком уровне.

«Современный учитель должен быть знаком и с достижениями смежных наук (физиологии, психологии, педагогики, эстетики) и применять их в своей практической деятельности. Таким образом, овладение профессией музыканта-педагога требует прежде всего общепедагогических, а уже затем профессиональных знаний. Ошибочно мнение, что музыкант-педагог прежде всего должен быть музыкантом, а педагогический опыт придёт само собой с годами».⁶ Учитель должен с самого начала быть хорошо подготовленным как в профессиональном, так и в педагогическом отношении. Музыкальные, художественные и артистические способности помогают творческому и своеобразному проявлению педагогической деятельности на основе высокого уровня развития общепедагогических способностей.

Теоретическая подготовка учителя музыки помогает ему глубже понимать явления музыкального искусства, закономерности истории и теории музыки и их взаимосвязь.

Изучение **истории и теории музыки** даёт возможность не только проводить уроки, но и организовывать внеурочную деятельность, поскольку обеспечивает следующие знания:

- общие закономерности развития музыкальной культуры и её связь с историческим и общественным развитием;
- основные особенности национальных композиторских школ;
- диалектику развития художественных стилей;
- эволюцию основных музыкальных жанров и форм.

Учитель одновременно приобретает следующие умения и навыки:

- интересно, образно и грамотно рассказывать детям о музыке, дополняя рассказ исполнением музыкальных произведений или их фрагментов;
- различать и представлять основные особенности того или иного музыкального стиля и направления, характеризовать стилевые особенности эпохи и композитора;
- свободно анализировать произведение, раскрывая закономерности реализации его образного содержания в контексте формы и выразительных средств;
- выявлять ключевые моменты музыкальной драматургии произведения.

Освоение дисциплины **«Гармония»** связано со следующими умениями:

- анализ ладофункционального развития произведения (тональный план, структура и функции аккордов);
- понимание фактурных особенностей;
- подбор аккомпанемента к заданной мелодии;

⁵ Б. Теплов — *Избранные труды*. Москва: «Педагогика», 1985

⁶ Б. Теплов — *Избранные труды*. Москва: «Педагогика», 1985

- свободная транспозиция.

Освоение курса «Сольфеджио» предполагает:

- чистое интонационное воспроизведение мелодии;

- удержание тональности на слух;
- чтение с листа и транспонирование.

Курс «Полифония» даёт знания:

- об основных закономерностях многоголосия;
- об эволюции полифонического письма и принципах развития современной многоголосной музыки.

Изучение дисциплины «Анализ музыкальных произведений» формирует у будущего учителя следующие умения:

- понимание исторических особенностей формы и стиля;
- комплексное восприятие формы, фактуры и гармонии произведения;
- осознанное понимание музыкальных форм в процессе исполнения и обучения.

Деятельность учителя музыки невозможно представить без **вокально-хоровой подготовки**, которая предполагает умение читать хоровую партитуру, дирижёрские навыки, а также знание методов работы с хором и постановки голоса. Дирижёрские навыки позволяют учителю-музыканту моделировать музыкальный образ и воплощать его в конкретном звучании. Учитель должен координировать свои движения: одной рукой дирижировать, другой — играть, показывать вступление, динамическое развитие, дыхание, фразы и т.д. В целом вокально-хоровая работа требует от учителя следить за чистотой интонации, ансамблем, артикуляцией, тембром, дыханием, темпом, динамикой, штрихами и фразировкой, а также учить школьников петь в соответствии с жестами дирижёра.

Учитель должен знать:

- особенности деятельности школьного дирижёра;
- вокально-хоровые программы различных ансамблей и хоров.

Профессиональную подготовку учителя невозможно представить без **исполнительской и концертмейстерской** деятельности. На уроке музыки учитель демонстрирует свои исполнительские навыки и умения. При этом предпочтение, как правило, отдаётся фортепиано, поскольку на уроке музыки учитель должен уметь исполнять на фортепиано многие произведения школьной программы, а также аккомпанировать при разучивании хоровых партитур и отдельных вокальных произведений. При отсутствии фортепиано, желательно, чтобы учитель владел игрой на аккордеоне или баяне.

В исполнительский репертуар учителя должны входить произведения, соответствующие различным возрастным группам. Во время исполнения учитель должен помнить, что музыка должна пробуждать творческое воображение детей и способствовать формированию ассоциативно-образного мышления. Одной из важных сторон подготовки учителя музыки является концертмейстерская работа.

Учитель должен уметь ярко, образно и эмоционально:

- аккомпанировать сольному и хоровому пению;
- показывать вступление хору и солисту;
- петь и одновременно аккомпанировать себе;
- читать с листа и транспонировать аккомпанемент в различные тональности;
- подбирать на слух аккомпанемент к известным мелодиям.

Особое внимание следует уделять владению учителем **методики музыкального воспитания**, поскольку она включает как профессиональные, так и психолого-педагогические знания и умения. Знание **методики преподавания музыки** помогает учителю правильно анализировать и осмысливать школьную программу, владеть методами работы, расширять возможности урока музыки с учётом особенностей конкретной школы и класса. Методика преподавания музыки раскрывает основные требования к учителю музыки в школе, освещает историю музыкального образования, определяет главные задачи музыкального воспитания, раскрывает содержание предмета «Музыка» и знакомит с видами музыкальной деятельности школьников. Методическая подготовка способствует более широкой и эффективной деятельности учителя в школе.

Заключение. Таким образом, урок музыки должен нести отпечаток личности учителя. Творчески подходить к уроку — значит ярко и убедительно раскрывать собственное отношение к музыке так же, как это делает композитор или исполнитель. Организуя соответствующую деятельность детей, учитель способствует тому, чтобы музыка достигала сознания каждого ученика и затрагивала их сердца, пробуждая эмоциональный отклик и активность в процессе исполнения и слушания музыки. Мерилом профессионализма педагога является способность интегрировать разные технологии и новейшие методики в процессе обучения и музыкального воспитания учащихся разных возрастов. В этом и заключается мастерство учителя.

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DECORATIVE PLASTER FINISHES AS MORPHOLOGICAL AND SEMIOTIC AGENTS IN THE ARTICULATION OF SPACE**Urazayeva L.***Bachelor of Fine Arts,**Lomonosov Moscow State University**Head of Decorative Finishes Studio, Tabigi Décor**Almaty, Kazakhstan***ДЕКОРАТИВНЫЕ ПОКРЫТИЯ СТЕН КАК ПЛАСТИЧЕСКИЙ И СЕМИОТИЧЕСКИЙ ФАКТОР ФОРМИРОВАНИЯ ПРОСТРАНСТВЕННОЙ СРЕДЫ****Уразеева Л.***Бакалавр изящных искусств**МГУ им. М. В. Ломоносова,**Руководитель студии декоративных покрытий**«Tabigi decor». Казахстан, г. Алматы*<https://doi.org/10.5281/zenodo.19050732>**Abstract**

The article is devoted to the study of decorative finishes in interior spaces in terms of artistic, morphological, and semiotic organization of walls within the spatial environment. Contemporary academic researches predominantly adopt an architectural and technical approach to decorative plaster, while the level of artistic reflection and the analysis of decorative finishes as visual, semiotic and culturally significant phenomena remain relatively limited. The scientific novelty of this article lies in its attempt to undertake a systematic art-historical analysis of decorative finishes not only as a construction element or design technique, but also as an artistic medium that shapes the semantic and visual perception of interior space. This dimension of the problem continues to be insufficiently examined in both domestic and international academic field. The article represents the outcome of the author's interdisciplinary research and includes a comprehensive analysis and systematization of existing academic sources in which decorative plaster is mentioned. The study is intended for a wide range of auditory, and might be useful to researchers, designers, art historians, architects, educators, and decorative artists.

Аннотация

Статья посвящена исследованию декоративных покрытий в интерьерах как средства художественной, пластической и семиотической организации стен в пространстве. В существующих научных исследованиях преобладает архитектурно-технический подход, тогда как уровень художественной рефлексии и анализ декоративной штукатурки как визуально-семиотического и культурно значимого феномена остаётся достаточно низким. Научная новизна работы заключается в попытке системного искусствоведческого анализа декоративных покрытий не только как строительного или дизайнерского приёма, но как художественного медиума, формирующего смысловое и визуальное восприятие интерьерного пространства; что на данный момент остаётся малоизученным аспектом в отечественных и зарубежных исследованиях. Данная статья является продуктом междисциплинарных исследований автора и включает в себя глубокий анализ и попытку систематизировать уже существующие научные материалы, где упоминается декоративная штукатурка. Данное исследование рассчитано на широкий круг читательской аудитории, и может быть использовано научными сотрудниками, дизайнерами, искусствоведами, архитекторами, преподавателями и мастерами-декораторами.

Keywords: decorative finishes, decorative plaster, spatial environment, interior design, walls, semiotics, decorative and applied arts

Ключевые слова: декоративные покрытия, декоративная штукатурка, пространственная среда, дизайн, стены, семиотика, декоративно-прикладное искусство

Формирование пространственной среды интерьера представляет собой сложный многоуровневый процесс, в котором конструктивные, функциональные и художественно-образные компоненты находятся в постоянном взаимодействии. Одним из ключевых элементов, определяющих характер восприятия внутреннего пространства, является оформление стен. Зачастую их значение выходит за пределы утилитарно-бытовой функции и проявляется в формировании смысловой структуры интерьера, его визуальной и семиотической организации.

Отделочные материалы и декоративные покрытия выступают не только как средства художественной выразительности, но и как носители культурных кодов, символических значений и исторической памяти. В этом контексте декоративная штукатурка может рассматриваться как специфический пластический инструмент, способный трансформировать плоскость стены в активный композиционный и смыслообразующий элемент пространства.

А.Г. Габричевский, анализируя морфологию художественного восприятия, отмечал, что значительная часть окружающей реальности остается недоступна нашему сознанию до тех пор, пока не будет осмыслена с художественной точки зрения. [2, с. 31-34] В этом смысле декоративную отделку поверхностей можно отнести к «неисчерпаемой сокровищнице реального», которая, тем не менее, редко притягивает к себе внимание простого обывателя. В этом исследовании автор предлагает читателю взглянуть на декоративную штукатурку созерцательно, определяя её место в мире, изучая историю возникновения, её культурное прошлое и настоящее; а также материальную и духовную составляющую, как знака прикладного искусства.

Актуальность исследования обусловлена возрастающим интересом к проблеме переосмысления традиционных отделочных техник в условиях современной архитектурной и дизайнерской практики. При этом исторический опыт применения декоративной штукатурки как пластического и имитационного инструмента остается недостаточно систематизированным в контексте его семиотического потенциала. Несмотря на широкое практическое применение декоративной штукатурки как в исторических, так и в современных интерьерах, её искусствоведческое и культурологическое осмысление остаётся фрагментарным.

Проблематика исследования заключается в выявлении двойственной природы декоративных покрытий: с одной стороны – как материально-пластического средства моделирования поверхности, с другой – как знаковой системы, способной транслировать представления о статусе, ценности материала, культурных традициях и художественных идеалах эпохи.

На сегодняшний день можно встретить возрастающий научный интерес к декоративным покрытиям в мировом профессиональном и научном сообществе. Например, в научном симпозиуме «Colloque: The Art and Industry of Stucco Decoration», проходившем в Риме в 2022, обсуждалось использование декоративной и гипсовой штукатурки в европейских интерьерах 15-18 веков, художественные техники, материалы, роль мастеров и другие вопросы.

Чтобы обозначить роль декоративной штукатурки в современном интерьере, лучше всего обратиться к её истокам. Точную дату возникновения декоративной штукатурки установить затруднительно, однако археологические и письменные источники свидетельствуют о широком применении имитационных и декоративных покрытий уже в древнейших цивилизациях – в Древнем Египте, Древней Греции и Древнем Риме.

В архитектуре Древнего Египта декоративная отделка стен выполняла не только эстетическую, но и символическую функцию. Уже в III тысячелетии до н. э. применялись приемы живописной имитации природных материалов. В гробнице Хетепхернеbti нижняя поверхность перекрытий была

расписана таким образом, что создавалась иллюзия конструкции из древесных стволов. По свидетельству археолога Доктора Г. Рейснера о раскопках в Гизе, в погребальных сооружениях V–VI династий широко использовалась имитация красного гранита: стены и потолки камер, высеченных в нуммулитовом известняке, покрывались штукатуркой и окрашивались так, чтобы воспроизводить фактуру и цвет дорогостоящего камня. [6]

Исследователи Рекс Энгельбах и Сомерс Кларк отмечают, что подобные приемы применялись и в храмовом строительстве, в частности в комплексе Дейр-эль-Бахри. Здесь обнаружены образцы имитационной живописи, воспроизводящей древесную текстуру с прорисовкой волокон. Следует подчеркнуть, что данные приемы представляли собой комплексную технологию: выравнивание основания путём нанесения штукатурного слоя и последующее создание имитационных росписей.

Технологическое осмысление штукатурных составов получает развитие в античной архитектурной теории. В трактате «Десять книг об архитектуре» Витрувий подробно описывает составы штукатурок на основе извести и мраморной крошки, а также методы их многослойного нанесения и полировки. Результатом становилась гладкая, глянцевая поверхность, способная имитировать полированный камень. [1]

Данные технологии легли в основу более поздних рецептов, известных сегодня как «венецианская штукатурка» – декоративное покрытие, воспроизводящее глубину и блеск мрамора.

В римском интерьере эпохи республики декоративная отделка стен становится неотъемлемой частью художественного оформления пространства. Исследование росписей Помпеи, Геркуланум, Стабии и Рима позволило выделить этапы развития настенной живописи до 79 г. н. э.

Наиболее ранний этап – так называемый первый помпейский стиль (II в. До н. э. – 80 г. До н. э.) – характеризуется имитацией облицовки стены мраморными плитами. Поверхность расчленялась на рельефные квадраты, отделенные желобками и окрашенные в различные тона с воспроизведением прожилок. Подобные приемы известны также в эллинистической традиции, в частности на острове Делос. [5]

Как отмечает искусствовед Георгий Соколов, особенностью первого стиля являлась рельефность кладки, выступающей из плоскости стены. Подобный эффект достигался именно благодаря использованию штукатурных наслоений, формирующих объемную структуру поверхности. [5]

Таким образом, декоративная штукатурка в античности выступала не только как средство живописной имитации, но и как пластический инструмент моделирования стены. В отличие от простой окраски, штукатурный слой позволял воспроизводить не только цвет и рисунок материала, но и его фактурную глубину, рельеф и полированную поверхность.

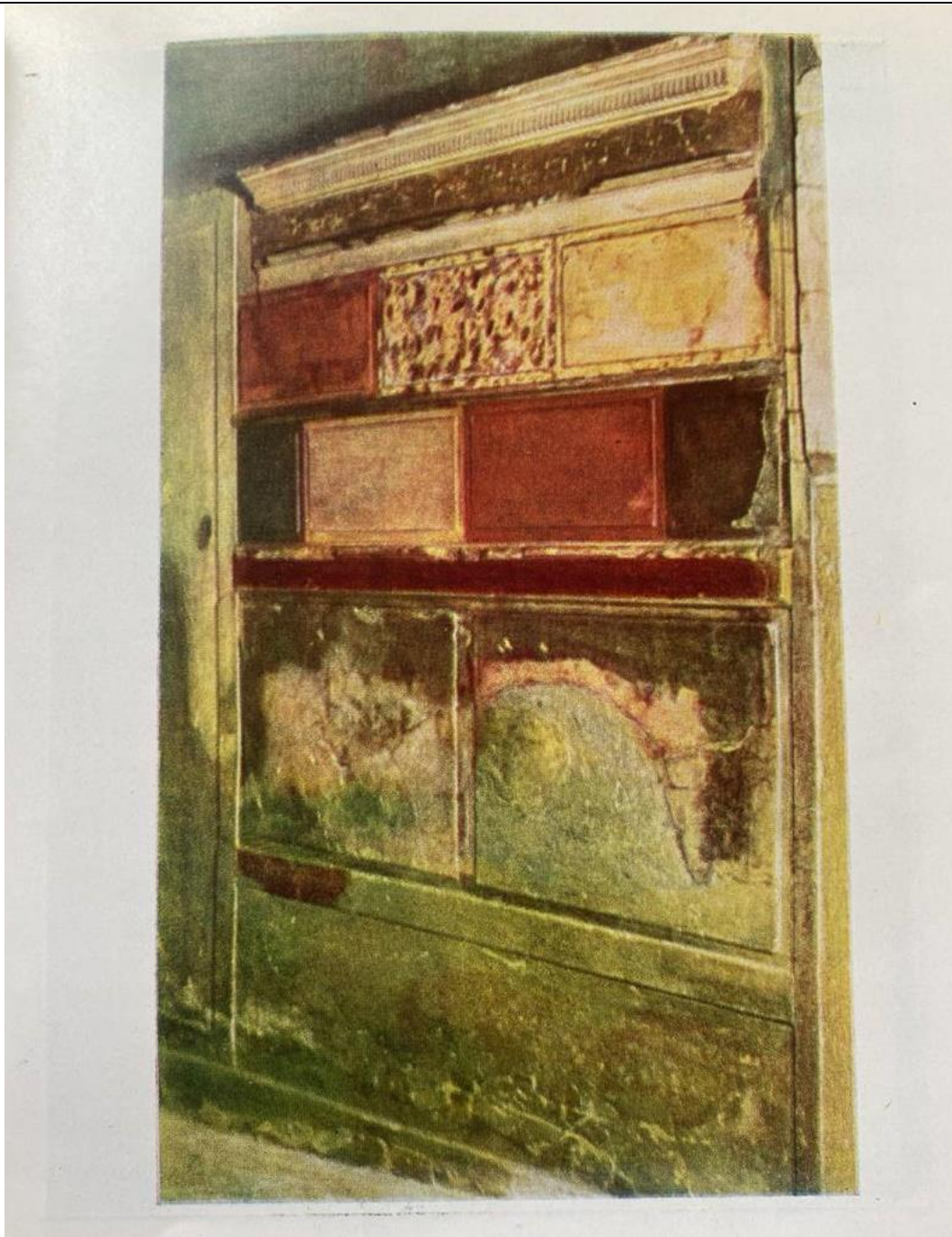


Рис 1 – Декоративная фреска первого помпейского стиля из Самнитского дома. Геркуланум. 2-1вв до н.э.

В эпоху Возрождения штукатурка применялась преимущественно для подготовки стен под росписи, а также для создания рельефных гипсовых орнаментов и барельефов. Однако её состав был приближен к современной декоративной штукатурке. Вот как описывает его Вазари: «А теперь, желая показать, как замешивается штукатурка, растолчем в каменной ступке мраморную крошку. Для этого берется лишь белая известь, полученная из мраморной крошки или из травертина, а вместо песка берется толченый мрамор, мелко просеянный и смешанный с известью; на две трети извести кладется одна треть толченого мрамора, более крупного или мелкого в зависимости от того, какой будет работа: более грубой или более тонкой.» [3, с.26]

Первое документально зафиксированное упоминание о применении декоративной штукатурки мраморино относится к строительному контракту с монахинями монастыря Санта-Кьяра на острове Мурано в 1473 году. В этом документе указано, что перед нанесением мраморино стену необходимо было подготовить раствором из извести и «соссіо pesto» (измельченной терракоты). Этот «соссіо pesto» получали из отходов кирпичного производства или из переработанной старой черепицы.

Соблюдая традицию преемственности поколений, декоративная штукатурка органично вплетается в канву современных интерьеров. Декоративная отделка стен является частью «мира вещей», окружающего человека наряду с другими знаками

прикладных искусств. Так, Лободанов А.П. в «Семиотике» выделяет 3 знаковых семиотических системы прикладных искусств – архитектура, костюм и утварь. [4, с. 465-466]

Декоративная штукатурка как элемент архитектурной среды и форма прикладного искусства может быть рассмотрена в качестве особого знака, обладающего двойственной природой – материальной и духовной. Подобно всякому объекту прикладных искусств, она представляет собой вещь, созданную в соответствии с определённым художественным замыслом и технологическим планом. При этом её вещественная сторона – фактура, пластика поверхности, состав материала, способ нанесения – непосредственно обусловлена её знаковой функцией, то есть способностью транслировать культурные, стилистические и художественные смыслы.

В качестве кода декоративной штукатурки выступают проектное решение (чертёж, эскиз, спецификация проекта) и технология исполнения, определяющие как её морфологические характеристики, так и визуально-пластический эффект. Понимание пространственной среды – её масштаба, ритмики, световой и цветовой организации предопределяет выбор фактурных решений, характер обработки поверхности и технологические приёмы создания декоративного слоя.

В культурно-историческом аспекте декоративная штукатурка фиксирует историю человека через организацию его предметно-пространственного окружения. Знаковая форма декоративной штукатурки, с одной стороны, выражает её функциональное назначение – акцентирование плоскости стены, формирование визуальной и тактильной иерархии пространства, – а с другой стороны, наиболее полно отражает стилевые характеристики эпохи её создания. Через фактуру, цвет, степень рельефности и

способ имитации материалов (мрамора, камня, ткани и др.) она маркирует принадлежность интерьеру к определённой художественной системе.

Таким образом, декоративная штукатурка принадлежит к архитектурным знакам в системе прикладных искусств и может быть интерпретирована как своеобразная метафорическая форма: её пластическая структура функционирует как знак, придающий пространству определённую идентичность и смысловую направленность.

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BIOLOGICAL SCIENCES

PLANT INDICATORS FOR ASSESSING THE ECOLOGICAL STATE OF FOREST ECOSYSTEMS IN THE TALYSH-LANKARAN REGION OF AZERBAIJAN

Aliyeva M.

PhD in biology, Associate Professor, Institute of Geography Public Legal Entity, Baku, Azerbaijan

<https://orcid.org/0000-0002-0298-8345>

<https://doi.org/10.5281/zenodo.19050734>

Abstract

Forest ecosystems of the Talysh-Lankaran region represent one of the most valuable natural complexes of the South Caucasus, characterized by high biodiversity and the presence of relict Hyrcanian forests. The present study examines the role of plant communities as indicators of the ecological state of forest ecosystems in the Talysh-Lankaran region. The research focuses on the analysis of dominant plant species, vegetation structure, and ecological characteristics of forest phytocenoses. The results demonstrate that plant indicators provide reliable information about environmental conditions, soil properties, and anthropogenic impacts. The implementation of phytomonitoring programs based on vegetation analysis can significantly improve the assessment and protection of forest ecosystems in the region.

Keywords: phytoindication, ecological monitoring, Talysh–Lankaran region.

Introduction. One of the most effective approaches for evaluating the ecological state of ecosystems is the use of biological indicators. Living organisms react to environmental changes through physiological, morphological, and population responses. Among biological indicators, plants are considered particularly valuable because they are directly influenced by soil properties, climate factors, and environmental disturbances [1, 2, 3, 4, 5, 6].

The Talysh-Lankaran natural region of Azerbaijan is known for its unique Hyrcanian forests, which represent ancient relict ecosystems formed during the Tertiary period. These forests are characterized by high species diversity and include numerous endemic and relict plant species. However, increasing anthropogenic pressure, deforestation, and climate variability have led to noticeable transformations in forest ecosystems [7, 8, 9, 10, 11, 12].

Under such conditions, phytomonitoring and phytoindication methods become important tools for assessing ecological changes. Plant communities can reflect environmental conditions through changes in species composition, vegetation structure, and physiological characteristics. Therefore, the study of plant indicators provides valuable information about the ecological stability and functioning of forest ecosystems [13, 14, 15, 16, 17, 18].

The aim of this study is to analyze plant indicators used for assessing the ecological state of forest ecosystems in the Talysh-Lankaran region and to evaluate their role in phytomonitoring of Hyrcanian forests.

Materials and Methods. The research was conducted in forest ecosystems of the Talysh-Lankaran natural region located in southeastern Azerbaijan. The area includes mountainous landscapes of the Talysh Mountains as well as lowland forest zones. The region is characterized by a humid subtropical climate with high annual precipitation ranging from 1200 to 1600 mm.

Forest vegetation in the region belongs to the Hyrcanian forest system and is dominated by broad-leaved

species such as: *P. persica*, *Q. castaneifolia*, *C. caucasica*, *A. subcordata*, *A. velutinum*. These species form complex multilayer forest communities with well-developed tree, shrub, and herbaceous layers. Vegetation surveys were conducted using standard geobotanical methods. Sample plots were established in representative forest areas to analyze species composition, vegetation structure, and ecological characteristics of plant communities. The following parameters were recorded: species composition of plant communities, dominance and abundance of species, structural characteristics of vegetation layers, ecological preferences of plant species, and indicators of environmental stress.

In addition, morphological and physiological parameters of selected plant species were evaluated as indicators of environmental conditions. The ecological condition of forest ecosystems was assessed using phytoindication methods based on the presence and distribution of indicator species. Special attention was given to species sensitive to changes in soil moisture, nutrient availability, and anthropogenic disturbance. Indicator analysis also included evaluation of vegetation diversity, dominance patterns, and ecological grouping of plant species [19, 20, 21, 22, 23, 24, 25].

Results and discussion. The studied forest ecosystems are characterized by complex vertical structure consisting of several vegetation layers. The tree layer is dominated by broad-leaved species typical of Hyrcanian forests. Among them, ironwood and chestnut-leaved oak play a particularly important role in the formation of forest communities.

The shrub layer includes species adapted to shaded and humid conditions, while the herbaceous layer contains numerous shade-tolerant plants. Several plant species were identified as important indicators of ecological conditions in the region. The presence of *P. persica* indicates well-preserved forest habitats with stable environmental conditions. This species is typically associated with fertile forest soils and high humidity. The species *Q. castaneifolia* serves as an indicator of fertile

mountain forest soils rich in organic matter. Oak-dominated forests often occur in areas with favorable ecological conditions. Moisture conditions are reflected by the distribution of *A. subcordata*, which usually grows along rivers and in wet forest habitats. Changes in the abundance of *C. caucasica* may indicate alterations in forest structure and light conditions. Meanwhile, *A. velutinum* is sensitive to microclimatic changes and forest canopy density.

In addition to species composition, several ecological parameters were identified as useful indicators of forest ecosystem condition: species diversity and richness; vegetation density and canopy structure; regeneration capacity of dominant tree species; morphological characteristics of leaves and shoots. Variations in these parameters can reflect environmental stress caused by anthropogenic activities or climate change.

The results demonstrate that plant communities provide valuable information about the ecological state of forest ecosystems in the Talysh-Lankaran region. Vegetation responds to environmental changes through shifts in species composition, structural characteristics, and physiological parameters. The use of indicator plant species is particularly effective for detecting early signs of ecosystem degradation. For example, changes in the abundance of dominant tree species may reflect alterations in soil fertility, moisture availability, or microclimatic conditions. Phytomonitoring based on vegetation analysis allows researchers to evaluate ecosystem stability and to identify potential threats to biodiversity. In the case of Hyrcanian forests, such monitoring is especially important due to their high conservation value and sensitivity to environmental disturbances. Furthermore, integrating vegetation analysis with soil and climatic data can provide a more comprehensive understanding of ecosystem dynamics.

Conclusion.

Forest ecosystems of the Talysh-Lankaran region represent unique natural systems characterized by high biodiversity and ecological importance. However, these ecosystems are increasingly affected by anthropogenic pressure and environmental changes. Plant indicators play a crucial role in assessing the ecological condition of forest ecosystems. The analysis of species composition, vegetation structure, and physiological characteristics of plants provides reliable information about environmental conditions and ecosystem stability. Implementing phytomonitoring programs based on plant indicators is essential for conserving Hyrcanian forests and sustainably managing forest resources in the Talysh-Lankaran region.

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CULTURAL SCIENCES

THE FUNCTIONING OF THE GEORGIAN ORTHODOX APOSTOLIC CHURCH IN THE DIASPORA AND THE ESTABLISHMENT OF GEORGIAN EPARCHIES ABROAD

Archimandrite Abo (Levan Chachua)

A third-year doctoral student at the Georgian Technical University, Faculty of Engineering Economics, Media Technologies and Social Sciences
<https://doi.org/10.5281/zenodo.19050736>

Abstract

This paper examines the history, canonical foundations, and pastoral strategies of the Diocese of Western Europe of the Georgian Orthodox Apostolic Church, established on October 17, 2002, with the blessing of Catholicos-Patriarch Ilia II and by decree of the Holy Synod. This ecclesiastical development responded to the spiritual needs of thousands of Georgian faithful living in emigration and marked a significant milestone in the modern history of the Georgian Church.

The author emphasizes the multifunctional role of the Church in the diaspora: it serves not only as a refuge of faith but also as the primary institution for preserving national identity, ensuring the transmission of Georgian language, culture, and traditions to future generations. The paper discusses the importance of Sunday schools, Georgian-language schools, and cultural centers in maintaining national-cultural identity.

Particular attention is devoted to the institution of catechesis and the problem of scriptural comprehension in diaspora contexts. The author argues that the use of comprehensible language in liturgical practice is essential for authentic knowledge of faith. The paper also addresses the necessity of clergy training, cooperation with local Orthodox jurisdictions, and preservation of memory regarding Georgia's occupied territories.

The research draws upon both ecclesiastical sources and contemporary scholarly literature on diaspora studies and Orthodox identity.

Keywords: Georgian Orthodox Church; Diocese of Western Europe; diaspora; emigration; pastoral care; national identity; catechesis; liturgical language; Georgian culture; Orthodox Christianity

Introduction

On October 17, 2002, with the benediction of His Holiness and Beatitude Ilia II, Catholicos-Patriarch of All Georgia, and by decree of the Holy Synod, the Diocese of Western Europe was established within the jurisdictional framework of the Georgian Orthodox Apostolic Church. This ecclesiastical act marked a significant development in the modern history of Georgian Orthodoxy, responding to the spiritual exigencies of thousands of Georgian faithful residing beyond the national borders. The establishment of this diocese represented a canonical recognition of the diaspora as an integral component of the Church's pastoral responsibility and ecclesiological self-understanding.

The subsequent administrative subdivision of this diocese—with the creation of the Dioceses of Great Britain and Ireland (2009), followed by the Dioceses of Germany and Austria, and Belgium and the Netherlands (2014)—reflects both the quantitative growth of Georgian Orthodox communities in Western Europe and the ecclesiastical maturation of the diaspora. Prior to this structural development, only three parishes functioned under patriarchal blessing: Strasbourg, Brussels, and Munich.

The Ecclesiological Significance of Diaspora Ministry

The founding of Georgian eparchies in Western Europe constitutes a unique ecclesiological development in the recent history of the Georgian Orthodox Church. By establishing dioceses under its direct jurisdiction, the Georgian Church articulated its theological and pastoral orientation toward tens of thousands of

compatriots living in emigration. This development positioned the Georgian Church within the broader Orthodox ecclesiastical landscape, assuming a fraternal canonical place alongside the Ecumenical Patriarchate of Constantinople and the Orthodox Churches of Russia, Serbia, and Romania, all of which maintain diocesan structures in the Western European region.

The stated objectives of this ecclesiastical structure encompass both spiritual and national dimensions: the pastoral care and spiritual protection of compatriots residing within diocesan boundaries, the preservation of their national and religious self-awareness, and support for Georgia's European integration process. These objectives reflect the dual character of Orthodox diaspora ministry, which simultaneously addresses soteriological concerns and cultural-identitarian preservation.

Demographic Context and Human Resources

Within the diocese encompassing the Kingdoms of Belgium and the Netherlands, approximately ten thousand Georgian compatriots currently reside. This demographic includes representatives of scientific and artistic professions, business entrepreneurs, and students pursuing higher education. This population constitutes a significant human resource capable of contributing not only to their countries of residence but also to addressing Georgia's economic challenges. However, as the text notes, the effective management of human resources requires substantial education and experience—a recognition of the complex dynamics of diaspora communities.

Historical Continuity and Contemporary Challenges

The phenomenon of Georgian emigration possesses historical precedents that inform contemporary ecclesiastical practice. From ancient times, Georgians abroad established educational centers and church-monastic institutions, receiving donations for their maintenance while enriching their homeland with spiritual achievements. This historical paradigm demonstrates that emigration, when properly oriented, can exert considerable influence on the future of the Georgian state and provide spiritual reference points for identity preservation.

Since the 1990s, Georgian emigrants have shared in both the sufferings and joys of their homeland—experiencing war, displacement, economic hardship, and spiritual crises. From this shared experience emerged cultural, social, and religious interests that subsequently gave rise to the formation of Orthodox communities. This organic development reflects the intrinsic connection between religious identity and national consciousness among Orthodox Georgians abroad.

Canonical Integration and Ecumenical Relations

The hierarchs governing Georgian dioceses in Western Europe have consistently participated in the Conference of Orthodox Bishops of their respective countries, functioning in accordance with the decisions of the IV Pan-Orthodox Conference in Chambésy (2009). This participation demonstrates the Georgian Church's commitment to pan-Orthodox unity and its recognition of the canonical order established by Orthodox Patriarchs for diaspora administration.

Pastoral Infrastructure and Cultural Preservation

Currently, of the seven parishes within the region, three possess their own church buildings. The diocese maintains Sunday schools and art studios, promoting Georgian spiritual culture while providing pastoral care for students and migrants. The text identifies the necessity of increasing clergy numbers to meet pastoral demands—a practical concern that reflects the challenges of ministering to dispersed communities.

The multinational and multiethnic environment of Western Europe, particularly in Belgium and the Netherlands, provides a context for intercultural dialogue that enriches both host societies and diaspora communities. This dialogue enhances value-based capacities, renders public goods more accessible, and fosters respect toward local communities while maintaining Georgian identity.

Catechetical Imperatives and Theological Education

The institution of catechesis receives particular attention as a matter of critical importance for diaspora churches. The text argues that catechetical education assumes even greater significance abroad than in Georgia itself, where dioceses possess general education schools and gymnasiums. In foreign contexts, faith must be supported by knowledge; the believer engages in constant cognitive process regarding self and surrounding world, for which catechetical schools provide essential formation.

The text poses rhetorical questions regarding baptismal preparation: How can candidates become acquainted with creation history, human history, and messianic prophecies without systematic catechetical instruction? Without reliance on catechetical schools as the tradition for transmitting teaching, and without systematic educational processes within every parish, gaps in divine knowledge cannot be adequately filled through Gospel reading and liturgical interpretation alone.

Scriptural Comprehension and Liturgical Language

A significant theological reflection concerns the comprehension of Holy Scripture. The text notes that the Apostles wrote Scripture in Koine Greek—the most widely spoken language of their time, easily understandable to contemporary audiences. This observation raises fundamental questions about language in Christian proclamation: without hearing, there can be no understanding; without understanding, no true cognition of salvific teaching.

The text advocates for careful attention to liturgical language, emphasizing the importance of hearing the Lord's proclamation in understandable language—so that what is heard does not require subsequent translation and theological interpretation. This reflection addresses a tension within Orthodox liturgical practice between preserving traditional liturgical language and ensuring congregational comprehension.

The text laments that contemporary practice often distances the faithful not only from Scripture in understandable language but also from liturgical poetry—those pearls articulated by holy and God-bearing Fathers through inspiration of divine knowledge. This concern reflects broader discussions within Orthodox theology regarding the relationship between liturgical tradition and pastoral accessibility.

Multifunctional Role of the Church in Diaspora

For diaspora Georgians, the Church represents more than a refuge for faith and ecclesial life that assists in acquiring Christian values. It has simultaneously assumed social, cultural, and educational functions. Pastoral practice has demonstrated that diaspora representatives require not only support in social and civic integration but also the establishment of Georgian-language institutions: schools, kindergartens, and courses in folklore, history, song, dance, theater, literature, and the arts for preservation of national-cultural identity and unity.

Practical Ecclesiastical Initiatives

The text enumerates specific areas of ecclesiastical engagement in the diaspora:

1. Sunday schools and religious education
2. Cooperation with diaspora youth and students
3. Support for Georgian statehood within diaspora communities
4. Preservation of memory regarding occupied territories (Abkhazia and Samachablo)
5. Engagement with penitentiary services abroad
6. Cooperation with local humanitarian associations, hospitals, and repatriation services
7. Collaboration with local Orthodox jurisdictions and associations

8. Support for research into historical and cultural legacy of Georgian emigrants
9. Organization of concerts, cultural evenings, and public activities
10. Support for church choirs, Georgian chant, and folklore preservation
11. Establishment of Georgian libraries and cultural resources

Conclusion

The experience of Georgian Orthodox dioceses in Western Europe represents a significant development in the modern history of the Georgian Apostolic Church. Through these structures, the Church addresses the spiritual needs of its diaspora while preserving national identity and cultural continuity. The challenges of catechetical education, scriptural comprehension, and liturgical language reflect broader theological questions facing Orthodox churches in diaspora contexts. The ultimate objective remains the salvation of the faithful—wherever they may live—and their formation as successful, strong bearers of value-based culture: good citizens, peacemakers, lovers of neighbor and homeland, and glorifiers of God.

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ECONOMIC SCIENCES

STRATEGIC DIRECTIONS FOR THE SUSTAINABLE DEVELOPMENT OF AZERBAIJAN'S INDUSTRIAL SECTORS

Zeynalgva S.

associate professor, Azerbaijan State University of Oil and Industry

Karimov K.

associate professor, Azerbaijan State University of Oil and Industry

Sadiqova A.

teacher, Azerbaijan State University of Oil and Industry

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Abstract

The article substantiates, from both scientific and practical perspectives, the importance of effective organization and management of sustainable industrial development based on the application of innovative technologies. The current state of the Republic's economy and the key factors influencing its development are analyzed in a logical sequence. Particular emphasis is placed on the need to reduce energy costs across all sectors of the economy in order to enhance energy efficiency, given the energy-intensive nature of industrial and agricultural production. The study also highlights the importance of increasing the level of fuel and energy supply and attracting greater investment.

At the same time, an econometric modeling methodology based on regression equations and a new linear model is proposed to examine the processes of assessing and improving the efficiency of human capital utilization. This approach is justified by the growing role of digital technologies, which require a qualitatively new framework for the formation and development of intellectual capital.

Keywords: industry; sustainable development; innovative technologies; human capital; knowledge; digitalization

Introduction

The dynamic and large-scale development of Azerbaijan's economy under modern conditions creates favorable prerequisites for long-term balanced growth that meets the economic, social, and environmental needs of future generations without compromising their ability to meet their own needs. Studies indicate that at the current stage of economic development, in order to build an economy aligned with international standards, it is essential to diversify the national economy, increase gross domestic product (GDP) per capita, improve the efficiency of human resource utilization, and introduce inclusive, innovative, and "smart" technologies across all sectors of the national economy.

Modern market conditions are characterized by intense competition and rapid changes in production technologies. Under these circumstances, increasing the flexibility of industries, ensuring prompt responses to market demands, and making sound strategic and operational decisions become critically important. The decisions adopted at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro [1] confirmed that transitioning to a sustainable development trajectory is a vital necessity for modern civilization.

From this perspective, three key principles can be identified that unify various interpretations of the concept of sustainable development.

First, environmental protection is recognized as a fundamental condition for the existence of human civilization. On the one hand, natural resources are being depleted, while on the other hand, waste generated by human activity exceeds the capacity of natural ecosystems for self-recovery.

Second, it is necessary to distinguish between the concepts of "economic growth" and "economic development." Growth reflects quantitative increases in the production of goods and services and is constrained by physical limits, whereas development implies qualitative transformation and diversification and is, in essence, unlimited in nature.

Third, sustainable development requires a fair allocation of resources. This involves a more equitable distribution of the global natural resource potential between developed and developing countries, driven by the need to satisfy the basic needs of less developed economies while simultaneously rationalizing consumption patterns in developed countries.

In modern market conditions, the effectiveness and long-term development of enterprises largely depend on the correct selection of strategic decisions that ensure the optimal use of available resources. Accordingly, enterprises must enhance their adaptability, respond swiftly to changing market conditions, and implement effective strategic and operational management practices.

The search for pathways toward global sustainable development is particularly relevant within Azerbaijan's development model. An analysis of the rapid economic progress of developed countries demonstrates that the successful implementation of innovative technologies in industrial sectors, combined with effective organizational and managerial frameworks, plays a decisive role in achieving sustainable development goals. For Azerbaijan, the development of sector-specific sustainable development models is therefore more relevant than abstract theoretical approaches.

In this context, the following key research objectives are identified:

- analysis of the role of innovation in ensuring the sustainability of industrial enterprises under modern economic conditions;
- examination of the impact of financial indicators on the sustainable development of enterprises;
- assessment of innovation development and its application in the sustainable growth of industrial enterprises;
- identification of factors and conditions that determine the sustainable economic development of industrial sectors;
- formation of priority technological, strategic, and integration frameworks reflecting the directions of innovative development within the domestic industrial complex;
- development of a sustainable development strategy based on international experience and determination of directions for its practical implementation [2].

Analysis of the Current State of Key Industries and Problem Identification: The development of industries is a key driving force of a country's economic

activity. The success of this process depends on the effectiveness of existing economic, legal, and institutional frameworks. Institutional assessment is of paramount importance for identifying key mechanisms, existing barriers, and potential opportunities that facilitate industrial development.

Domestic and foreign investments play a crucial role in the growth of the industrial sector. The volume of investment is closely linked to the country's business environment, tax policy, and the state of infrastructure. The impact of government support measures for various sectors of the economy—including subsidies, tax incentives, and the promotion of domestic and foreign investment, as well as other policy initiatives—should be assessed separately. Such an analysis makes it possible to determine the extent of the state's role in industrial development.

The volume of domestic and foreign investment in fixed assets in the industrial sector at current prices for the period 2018–2024 is presented in Table 1.

Table 1

Domestic and foreign investments in fixed assets in the industry for 2018-2024 (AZN million)

Indicators	Years			
	2018	2020	2022	2024
All industries, Including:: foreign investments domestic investments	9258,0 4411,3 4846,7	7507,3 3169,1 4338,2	7172,1 2891,3 4280,8	8405,7 3275,9 5129,8
Mining industry, Including: foreign investments domestic investments	5670,5 3443,8 2226,7	4817,1 3085,0 1732,1	4983,8 2833,6 2150,2	6135,5 3275,9 2859,6
Processing industry, Including: foreign investments domestic investments	2466,4 798,0 1668,4	2018,0 13,0 2005,0	1202,2 52,9 1149,3	916,8 - 916,8
Electricity, gas and steam generation, distribution and supply, Including: foreign investments domestic investments	490,0 0,4 489,6	482,9 44,7 438,2	689,8 4,8 685,0	1082,4 - 1082,4
Water supply, waste treatment and processing, Including: foreign investments domestic investments	631,1 169,1 462,0	189,3 26,4 162,9	296,3 - 296,3	271,0 - 271,0

The data presented in Table 1 indicate that over the past six years the volume of foreign investment has declined, while domestic investment has increased. This trend suggests that Azerbaijan has sufficient potential to support the development of industrial sectors through domestic financial resources.

Industrial production is widely regarded as one of the key indicators of economic growth. The industrial sector accounts for a significant share of employment; therefore, particular attention should be paid to manufacturing and construction. Prices of raw materials and energy resources used in industrial production have a direct impact on inflation. Moreover, price fluctuations

in industries such as oil, gas, and metallurgy exert spill-over effects on other sectors of the economy.

With regard to the manufacturing sector, as well as the extractive industry, it is necessary to analyze indicators such as the number of enterprises (including non-state enterprises), the number of individual entrepreneurs engaged in industrial activities, the value of industrial output (goods, works, and services), and the share of manufacturing output in the total industrial output of the country. An increase in these indicators has been observed, as shown in Table 2.

Along with the development of the manufacturing industry, a number of challenges also arise, including

issues related to raw material supply, waste management, and technological competition. Rapid technological progress has intensified competition among firms. In the future, the manufacturing industry is expected to develop further through the application of artificial intelligence, automated production systems, and nanotechnologies. These innovations will make a substantial contribution to industrial development across various dimensions.

The development of human capital has consistently played a leading role as a key factor in ensuring

the sustainability of industrial sectors. To assess the country's sustainable development more accurately, it is necessary to analyze gross domestic product (GDP) indicators, including total GDP volume, sectoral structure, GDP per capita, and GDP dynamics in comparison with previous periods. A comparative analysis of these indicators provides a comprehensive assessment of economic sustainability. The relevant data are presented in Table 2.

Table 2

Gross Domestic Product (GDP) production for 2018-2024					
Indicators	Size unit	Years			
		2018	2020	2022	2024
GDP	Milyard AZN	81,7	92,9	133,8	123,0
Industry	%	41,4	42,5	51,1	40,5
Trading	%	10,0	10,1	8,2	10,0
Construction	%	7,3	5,9	4,8	6,2
Transportation	%	6,0	6,9	6,0	6,2
Agriculture	%	5,7	5,9	4,8	5,5
Information and communication	%	1,8	1,8	1,4	1,7
Public catering areas	%	2,4	1,3	1,6	2,2
Other areas	%	16,7	17,2	14,7	18,6
To each person of the population falling GDP	AZN	8247,0	9269,3	13292,2	12114,5

To ensure the efficient development of the economy and improve the quality of life of the population, the following energy-related challenges require urgent attention:

- Reducing the energy intensity of the economy and energy consumption in the social sector.

- Decreasing energy dependence by increasing the supply of domestic fuel and energy resources, diversifying sources, importing energy resources as necessary, and creating reserves of fuel and energy resources.

- Modernizing the fixed assets of the fuel and energy complex (FEC) and improving the reliability, efficiency, and environmental sustainability of its enterprises and industries.

- Increasing investment in renewable energy sources.

- Promoting social responsibility among businesses and society.

- Strengthening public-private partnerships to support sustainable development.

- Ensuring sustainable development through improvements in education and increased social responsibility, among other measures [3].

Solutions for Sustainable Development of Industry: The strategic goal of developing the Republic's industrial complex is to improve the quality of life of the population and create new competitive industries through the efficient utilization and development of sustainable core industrial potential.

In Azerbaijan, the production of basic industrial products remains significantly lower than in developed countries. The economic system, which remained largely unchanged over the past two decades, has led to a shortage of qualified engineers, designers, and production managers.

According to E.E. Rumyantsev, in his work *New Economic Encyclopedia*, greater economic results can be achieved through the application of innovations, which constitute the essence of a progressive state strategy and an objectively necessary component of economic development. He describes the innovation process as a system of reactions primarily responding to changes in market demand, involving various elements of the system and their interactions. The outcome of this process is an adaptive response to evolving market requirements [4].

In the innovative economies of developed countries, intellectual resources constitute one of the most important assets of many firms. Experts indicate that this sector accounts for a significant share of GDP and is often referred to as the intellectual production sector.

Amidst the globalization of the world economy, Azerbaijan faces the need for efficient utilization of economic resources, requiring qualitative changes based on new knowledge. The economist P. Strasman emphasizes that knowledge is a primary source of sustainable competitive advantage. In his monograph on knowledge management, he identifies two approaches to managing knowledge:

1.Knowledge as information management, where information systems play a central role.

2.Knowledge as people management, which focuses on the development of knowledge processes and the enhancement of employee competencies to improve organizational performance. Knowledge competence is a multifaceted concept that encompasses both operational and strategic outcomes and should be considered at individual and organizational levels.

Based on research by leading scholars, the main tasks of intellectual resource management can be summarized as follows:

- Identifying priorities for scientific and technological development within the organization;
- Establishing and utilizing knowledge portals;
- Developing and implementing international scientific and technical cooperation programs;
- Increasing the volume of research and experimental-design activities;
- Regularly updating and analyzing the relevance of the knowledge base;
- Developing and effectively managing an intellectual property portfolio.

From these concepts, the elements of knowledge competencies can be defined as follows:

1. Knowledge assets – all explicit and tacit knowledge available in the organization. Knowledge assets support the achievement of strategic organizational goals and are considered intangible resources. Knowledge in an organization is continuously evolving.

2. Knowledge learning – an ongoing process that generates new knowledge and enhances existing knowledge within the organization.

3. Intellectual management – the practical application of knowledge within the enterprise. This competency reflects the organization's ability to use knowledge where and when it is needed. Additionally, knowledge management fosters the development of knowledge assets and continuous learning.

In the context of modern innovation-driven economies, the concept of **human capital**, which integrates knowledge and competencies, has become increasingly important. The efficiency of production, commercial success, and profitability of organizations largely depend on the availability, effective utilization, and further development of human capital. A key objective is to enhance the role of education and science in developing human capital to support sustainable economic growth and national competitiveness.

Many scholars highlight that competencies arising from the purposeful management and use of human resources to gain a competitive advantage in the market are known as **knowledge management competencies** (Figure 1).

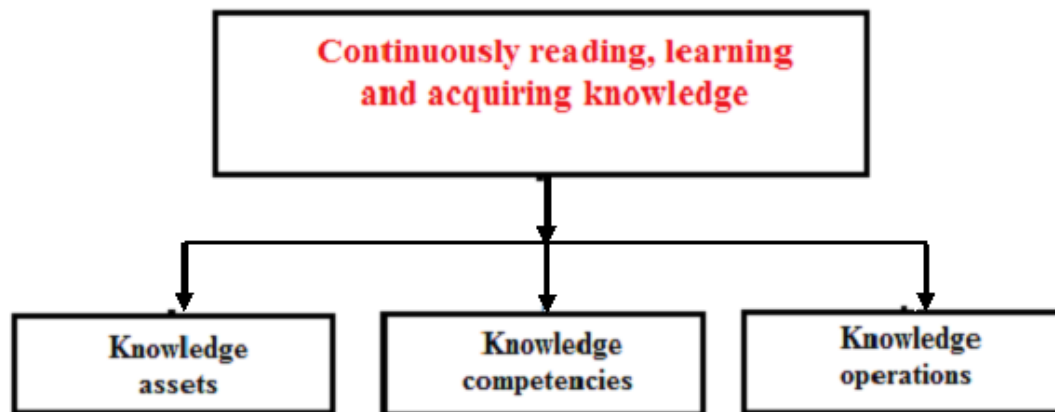


Fig.1. Research on Human Capital and Knowledge Management in the Digital Economy

Research shows that organizations seeking a competitive advantage must focus on critical competencies and knowledge management skills [7]. Intellectual knowledge management is a dynamic organizational phenomenon composed of interdependent processes, including the acquisition of knowledge, its transformation into a usable form, and its practical application. As illustrated in Figure 1, effective knowledge management integrates strategy, leadership, and organizational culture, which are critical success factors. Additionally, technology, organizational structure, and culture provide the necessary infrastructure for managing knowledge assets.

To enhance the competitiveness of Azerbaijan's economic sectors, enterprises must create, maintain, and share organizational knowledge. Knowledge sharing and the exchange of experience are equally important. According to most scholars, the main factors contributing to economic growth through human capital include:

-Knowledge, experience, competence, and education;

- Acquired qualifications;
- Cultural and ethical environment;
- Creative thinking;
- Health, work ability, innovation capacity, professional experience, and training;
- Level of well-being;
- Rational, physical, intellectual, and psychological potential.

The use of digital technologies requires a qualitatively new approach to developing personal intellectual capital, making it a key priority for modern enterprises and innovative firms. Digitalization should serve as a leading factor in optimizing intellectual capital use, improving production and logistics efficiency, reducing costs, and enhancing workforce productivity [5].

There is currently a structural imbalance in the financing of the education sector in Azerbaijan. To address this, it is proposed to focus on:

- Providing social assistance to unemployed and low-income citizens;
- Encouraging competition and involving the private sector in social service provision;

- Increasing employee professionalism;
- Implementing regional training programs and targeted personnel financing;
- Strengthening the material and technical base of medical and social institutions;
- Ensuring accessible information and communication infrastructure for citizens and businesses [8].

Modern research emphasizes that evaluating the effectiveness of human capital requires both quantitative and qualitative indicators. To support this, an **econometric modeling methodology** based on regression analysis is employed to study the formation and development of human capital.

The effectiveness of human capital, particularly its educational determinants, can be expressed as:

$$W = y_0 + y_1S + y_2X + y_3X^2 + U, (1)$$

where: W – salary, AZN man; y_0, y_1, y_2, y_3 – coefficients of the regression equation; S – years of general education; X – work experience (actual turnover of human capital in the labor market, years); U – factors not included in the model.

In efficient labor markets, the value of human capital is closely linked to wages. Empirical evidence from Germany and the USA demonstrates that higher professional qualifications are associated with higher average income, signaling market demand for knowledge-based competencies and stimulating professional skill development.

For employees in production and managerial positions, competencies such as **foreign language proficiency** and **Big Data skills** are increasingly important. The ability to work with large digital datasets and effectively use digital technologies is essential. To analyze these factors comprehensively, we propose the following **new linear model**:

$$\ln W = x_0 + x_1Y + x_2L + z_1E + z_2G_e + z_3B_0 + \sum_{i=1}^N z_i R_{ei} + \sum_{j=1}^K z_j P_{nj}, (2)$$

where $x_0, x_1, x_2, z_1, z_2, z_3$ – quantity-quality constants; Y – age; L – work experience; E – general education; G_e – gender; B_0 – professional level; R_{ei} – sector of employment; P_{nj} – enterprise-level determinants.

Using this model, the following main development directions for efficient human capital utilization in Azerbaijan's digital economy are proposed:

- Automation of production, development of artificial intelligence, and transformation of organizational structures to meet evolving workforce requirements.
- Emphasis on skills and qualities that ensure future success rather than relying solely on past professional experience.
- Continuous updating of required competency lists.
- Increasing employees' programming and digital skills.
- Maximizing the use of modern technologies in roles where AI and robotics complement human labor.
- Promoting educational engagement, researching learning processes, analyzing outcomes, and applying findings in practice.

The transition to digital technologies requires flexibility and personalization of processes, changes in organizational culture, optimization of management models, and adaptation of training programs [6].

Conclusion

1. To prevent a decline in hydrocarbon production in the oil and gas sector—the backbone of Azerbaijan's energy supply—and to ensure sustainable development, a **Strategic Plan for the development and exploitation of hydrocarbon deposits** has been developed.

2. Leading economies such as the USA, EU, UK, China, and Japan recognize hydrogen as a critical element in decarbonization. Studying its storage requirements and integration with renewable energy is vital for Azerbaijan.

3. A systematic approach to industrial policy should consider the real needs and resources (technological development, resource base, human capital, organizational mechanisms, and institutions) necessary for the development of the industrial sector as an economic system.

4. A strong production infrastructure must be established to ensure a successful transition to sustainable development, reduce dependence on external markets, and diversify the economy.

5. Azerbaijan's integration into the global economy should follow an **innovation-driven growth model**, emphasizing education and science, the efficient use of human capital, and the combination of knowledge and skills to enhance organizational performance and national competitiveness.

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MATHEMATICAL SCIENCES

ON THE GEOMETRY OF DEVELOPABLE SURFACES IN STRATIFIED INCOMING VORTICAL FLOW OVER A CONE

Milyute E.

Milyus A.

IRG "LITAVEM-3", Vilnius, Lithuania

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Abstract

The paper considers a mathematical model of the formation of a developing surface in a stratified oncoming vortex flow when interacting with a conical obstacle. Similar structures arise in the hydrodynamics of swirling flows, atmospheric vortex systems, as well as in a number of technical applications related to turbomachines and aerodynamic devices. It is shown that the surface of the vortex layer descending from the cone can be described as a spiral ruled surface, the geometry of which is determined simultaneously by the shape of the obstacle and the structure of the oncoming flow. For the description, a system of equations of a stratified fluid in the Boussinesq approximation is used. In cylindrical coordinates, a parameterization of the surface is introduced through the radius function $r(\theta, z, t)$, depending on the angular coordinate, vertical coordinate and time. Expressions are obtained for the surface normal, coefficients of the first and second quadratic forms, Gaussian and mean curvature. The condition for the developability of the surface is derived and the criterion for the separation of the vortex layer from the surface of the cone is formulated. It is shown that the horizontal sections of the surface under consideration have the shape of an Archimedes spiral, and the pitch of the spiral is determined by the ratio of the layer descent velocity to the local angular velocity of the flow. The resulting model allows us to relate the geometry of the resulting surface with the parameters of the oncoming stratified vortex flow and the cone angle.

Keywords: oncoming stratified flow, matter transfer, vortex dynamics of substance, circulation, twist, turbulence, vortex layer separation criterion, cone cavity, developable surface, Gaussian curvature, vortex-sheet separation line, torse.

1. Introduction

Swirling stratified flows are widely encountered both in natural phenomena and in engineering problems [4-8]. Examples of such structures are atmospheric vortices, water funnels, flows in reactors, vortex structures in turbomachines and vortex separation devices. One of the characteristic features of such flows is the formation of complex vortex surfaces and spiral layers that arise when the flow interacts with geometric obstacles.

Of particular interest is the case of interaction of a swirling flow with axisymmetric bodies. If the oncoming flow has both axial velocity and azimuthal swirl, then when it flows around bodies of rotation, the formation of spiral vortex surfaces is possible. Such surfaces can come off the edge of an obstacle and spread in space in the form of spiral shells.

A developable surface is understood as a surface with zero Gaussian curvature. Such surfaces can be turned flat without stretching or compressing. Classic examples include cylindrical surfaces, cones and helicoids. However, in hydrodynamic problems, more complex surfaces may arise that retain local linearity and approach developable surfaces.

The purpose of this work is to construct a mathematical model that allows us to describe the geometry of such a surface and relate its shape to the flow parameters and the geometry of the obstacle. In particular, it is necessary to determine:

- structure of the oncoming stratified vortex flow;
- geometric description of the surface of the vortex layer;
- normal and curvature of the surface;
- condition of developability of a surface;
- criterion for the separation of the vortex layer from the surface of the cone.

2. Basic equations of stratified flow

To solve the problem under consideration, we introduce the function

$$v = (ur, u\theta, uz) \quad (1)$$

in cylindrical coordinates (r, θ, z) .

The basic equations of motion of a stratified fluid in the Boussinesq approximation have the form

$$\nabla \cdot \mathbf{v} = 0,$$

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho_0} \nabla p + b \mathbf{e}_z, \quad (2)$$

$$\frac{\partial b}{\partial t} + (\mathbf{v} \cdot \nabla) b = 0.$$

Here p is pressure, ρ_0 is reference density, b is buoyancy. The evolution of stratification is described by the transport equation

$$\frac{\partial b}{\partial t} + (\mathbf{v} \cdot \nabla)b = 0. \quad (3)$$

For a stable stratified liquid, you can take

$$b = -N^2 z \quad (4)$$

where N is Brunt–Väisälä frequency, b is buoyancy.

3. Basic field of the oncoming vortex flow

The incoming vortex flow is assumed to be axisymmetric. Its structure is defined by the distributions of the axial and azimuthal velocities. We employ a convenient model of the axisymmetric flow upstream of the cone.

$$u_z = U(z),$$

$$u_\theta = \Omega(z) r \quad \text{или} \quad u_\theta = \frac{\Gamma(z)}{2\pi r} (1 - e^{-r^2/a^2}), \quad (5)$$

$$u_r \approx 0.$$

where $U(z)$ is the incoming axial velocity, $\Omega(z)$ is the local angular velocity, and Γ is the circulation. To satisfy the incompressibility condition, a weak radial component is introduced.

$$u_r = -\frac{r}{2} \frac{\partial U}{\partial z}. \quad (6)$$

Then

$$\frac{1}{r} \frac{\partial(r u_r)}{\partial r} + \frac{\partial u_z}{\partial z} = 0. \quad (7)$$

4. Geometry of a Conical Obstacle

When such a flow interacts with a conical obstacle, a vortex surface $F(r, \theta, z, t) = 0$ is formed, issuing from the surface of the cone. The geometry of the obstacle in the form of a cone is described by the radius function

$$r_c(z) = r_0 + (z - z_0) \tan \alpha, \quad (8)$$

where α is the cone half-angle, z_0 is the level where the cone begins, and r_0 is the radius at the cross-section $z = z_0$. In Cartesian coordinates, the surface of the cone is defined by the equation:

$$x^2 + y^2 = r_c^2(z).$$

In cylindrical coordinates (r, θ, z) , it can be written as

$$u_z = U(z, t), \quad u_\theta = \Omega(z, t) r, \quad u_r = -\frac{r}{2} \partial_z U(z, t), \quad (9)$$

with buoyancy b (4).

The normal to this surface can then be expressed as

$$\mathbf{F}_c(r, z) = \mathbf{r} - r_c(z) \mathbf{e}_z = 0, \quad \nabla F_c = \mathbf{e}_r - \tan \alpha \mathbf{e}_z \quad (10)$$

To describe the resulting surface, a cylindrical function is introduced.

$$r(\theta, z, t) = r_c(z) + a(z, t)(\theta - \theta_0(z, t)). \quad (11)$$

This formula defines a helical surface, which in Cartesian coordinates can be written in parametric form.

$$\mathbf{X}(\theta, z, t) = (r(\theta, z, t) \cos \theta, r(\theta, z, t) \sin \theta, z). \quad (12)$$

Horizontal cross-sections of this surface have the form of an Archimedean spiral. The pitch of the spiral is determined by the function

$$a(z, t) = \frac{V_s(z, t)}{\Omega(z, t)}. \quad (13)$$

Here $V_s(z, t)$ is the velocity at which the vortex sheet leaves the surface of the cone. In the simplest model, it is proportional to the axial flow velocity.

$$V_s(z, t) = \mu U(z, t) \sin \alpha. \quad (14)$$

Thus, the main equation of the surface is obtained

$$r(\theta, z, t) = r_0 + (z - z_0) \tan \alpha + \mu \frac{U(z, t) \sin \alpha}{\Omega(z, t)} (\theta - \theta_0(z, t)). \quad (15)$$

Further analysis of the surface requires the computation of its geometric characteristics. The derivatives of the radius function take the form

$$r_\theta = a(z, t), \quad (16)$$

$$r_z = \tan \alpha + a_z(\theta - \theta_0) - a \theta_{0z}.$$

Thus, we obtain an implicitly developable helical surface, for which the Riemann helicoid is a particular case:

$$F(r, \theta, z, t) = r - r_c(z) - a(z, t)(\theta - \theta_0(z, t)) = 0 \quad (17)$$

where r_c determines the geometry of the cone, $\theta_0(z, t)$ is the phase line of the vortex-sheet shedding, $a(z, t)$ is the local pitch of the spiral unfolding, and μ is the coupling coefficient between the flow and the cone surface.

5. The condition that the surface is a material surface If the surface is transported by the flow, it must satisfy the transport equation.:

$$\frac{\partial F}{\partial t} + u_r \frac{\partial F}{\partial r} + \frac{u_\theta}{r} \frac{\partial F}{\partial \theta} + u_z \frac{\partial F}{\partial z} = 0. \quad (19)$$

For our form, we have

$$F_r = 1, \quad F_\theta = -a(z, t), \quad F_z = -r'_c(z) - a_z(\theta - \theta_0) + a\theta_{0z}, \quad (20)$$

$$F_t = -a_t(\theta - \theta_0) + a\theta_{0t}.$$

Thus, the complete equation takes the form:

$$-a_t(\theta - \theta_0) + a\theta_{0t} + u_r - \frac{u_\theta}{r} a + u_z \left(-r'_c(z) - a_z(\theta - \theta_0) + a\theta_{0z} \right) = 0. \quad (21)$$

Since

$$r'_c(z) = \tan \alpha, \quad (22)$$

we obtain a closed-form PDE governing the evolution of the spiral developable surface:

$$-a_t(\theta - \theta_0) + a\theta_{0t} + u_r - a \frac{u_\theta}{r} + u_z \left(-r'_c(z) - a_z(\theta - \theta_0) + a\theta_{0z} \right) = 0. \quad (23)$$

6. Developability Condition for the Parametric Representation of the Surface

If we wish to determine a ruled developable surface, using (12–13) we can write

$$\mathbf{X}(s, \lambda, t) = \mathbf{C}(s, t) + \lambda \mathbf{d}(s, t), \quad (24)$$

subject to the **zero Gaussian curvature condition**, which leads to **the unfolding of a stratified vortex shell** shed from the conical obstacle

$$\det(\mathbf{C}_s, \mathbf{d}, \mathbf{d}_s) = 0. \quad (25)$$

7. A Simple Physical Interpretation of the Tangency and Detachment Conditions of a Stratified Vortex Layer

On the cone surface, the no-penetration condition holds:

$$\mathbf{v} \cdot \mathbf{n}_c = 0 \quad (26)$$

Substituting the velocity components, we obtain:

$$u_r - u_z \tan \alpha = 0 \quad (27)$$

This condition ensures that the flow is tangent to the cone surface.

If we have $u_r - u_z \tan \alpha > 0$, (28)

the flow begins to deviate from the surface, corresponding to the onset of vortex-surface shedding. The model implies that:

$$\frac{dr}{d\theta} = a(z, t) = \mu \frac{U(z, t) \sin \alpha}{\Omega(z, t)}. \quad (29)$$

Thus, we arrive at the following conclusions:

- increasing α , leads to a stronger opening of the surface;
- increasing U , causes the surface to unwind more rapidly
- increasing Ω , results in tighter spiral turns;
- stratification, through $\mathbf{N}$, affects the vertical coupling of the layers and the admissible forms of $U(z, t)$ and $\Omega(z, t)$.

8. Surface Derivatives

For surface (13), where $r(\theta, z, t)$ is taken from Eq. (12), and $r_c(z)$ from Eq. (8), we derive in the following analysis the normal vectors, the metric, the curvatures, and the condition for detachment from the cone.

Let us denote

$$r_\theta = \frac{\partial r}{\partial \theta} = a(z, t), \quad (30)$$

$$r_z = \frac{\partial r}{\partial z} = r'_c(z) + a_z(\theta - \theta_0) - a\theta_{0z}.$$

Since the tangent of the angle α is equal to $r'_c(z)$ (22), we have

$$r_z = \tan \alpha + a_z(\theta - \theta_0) - a\theta_{0z}. \quad (31)$$

From this we obtain the derivatives of the parametrization:

$$\mathbf{X}_\theta = (r_\theta \cos \theta - r \sin \theta, r_\theta \sin \theta + r \cos \theta, 0), \quad (32)$$

$$\mathbf{X}_z = (r_z \cos \theta, r_z \sin \theta, 1).$$

9. Unnormalized and unit normal vectors

Unnormalized normal vector:

$$\mathbf{N} = \mathbf{X}_\theta \times \mathbf{X}_z. \quad (33)$$

after calculation gives

$$\mathbf{N} = (r_\theta \sin \theta + r \cos \theta, -(r_\theta \cos \theta - r \sin \theta), -r r_z) \quad (34)$$

Or with $r_c = a$:

$$\mathbf{N} = (a \sin \theta + r \cos \theta, -a \cos \theta + r \sin \theta, -r r_z). \quad (34^*)$$

Its length is given by:

$$|\mathbf{N}| = \sqrt{r^2 + r_\theta^2 + r^2 r_z^2}. \quad (35)$$

From this we obtain the unit normal vector:

$$\mathbf{n} = \frac{1}{\sqrt{r^2 + r_\theta^2 + r^2 r_z^2}} (r_\theta \sin \theta + r \cos \theta, -r_\theta \cos \theta + r \sin \theta, -r r_z). \quad (36)$$

10. First Fundamental Form of the Surface

The metric coefficients are:

$$\begin{aligned} E &= \mathbf{X}_\theta \cdot \mathbf{X}_\theta = r_\theta^2 + r^2, \\ F &= \mathbf{X}_\theta \cdot \mathbf{X}_z = r_\theta r_z, \\ G &= \mathbf{X}_z \cdot \mathbf{X}_z = 1 + r_z^2. \end{aligned} \quad (37)$$

From them we have:

$$E = r^2 + a^2, \quad F = a r_z, \quad G = 1 + r_z^2. \quad (38)$$

11. Second Fundamental Form

We need the second derivatives; thus, we have

$$\begin{aligned} \mathbf{X}_{\theta\theta} &= ((r_{\theta\theta} - r) \cos \theta - 2r_\theta \sin \theta, (r_{\theta\theta} - r) \sin \theta + 2r_\theta \cos \theta, 0), \\ \mathbf{X}_{\theta z} &= (r_{\theta z} \cos \theta - r_z \sin \theta, r_{\theta z} \sin \theta + r_z \cos \theta, 0), \\ \mathbf{X}_{zz} &= (r_{zz} \cos \theta, r_{zz} \sin \theta, 0). \end{aligned} \quad (39)$$

For our model we have:

$$r_{\theta\theta} = 0, \quad r_{\theta z} = a_z. \quad (40)$$

where are the coefficients of the second form:

$$e = \mathbf{n} \cdot \mathbf{X}_{\theta\theta}, \quad f = \mathbf{n} \cdot \mathbf{X}_{\theta z}, \quad g = \mathbf{n} \cdot \mathbf{X}_{zz}. \quad (41)$$

After simplification through the non-normalized normal $\mathbf{N}$:

$$\begin{aligned} e^* &= \mathbf{N} \cdot \mathbf{X}_{\theta\theta} = r(2a^2 + r^2), \\ f^* &= \mathbf{N} \cdot \mathbf{X}_{\theta z} = r(a_z - r_z), \\ g^* &= \mathbf{N} \cdot \mathbf{X}_{zz} = r r_{zz}. \end{aligned} \quad (42)$$

Then we get for each e, f, g :

$$e = \frac{e^*}{|\mathbf{N}|}, \quad f = \frac{f^*}{|\mathbf{N}|}, \quad g = \frac{g^*}{|\mathbf{N}|}. \quad (43)$$

12. Gaussian and Mean Curvatures

The Gaussian curvature is defined by the formula:

$$K = \frac{eg - f^2}{EG - F^2}. \quad (44)$$

Since
we obtain

$$EG - F^2 = (r^2 + a^2)(1 + r_z^2) - a^2 r_z^2 = r^2(1 + r_z^2) + a^2, \quad (45)$$

$$K = \frac{e^* g^* - (f^*)^2}{(r^2(1 + r_z^2) + a^2)^2}. \quad (46)$$

That is, after substituting our expressions, we obtain an extended form for determining the Gaussian curvature at local points

$$K = \frac{r^2(2a^2 + r^2) r_{zz} - r^2(a_z - r_z)^2}{(r^2(1 + r_z^2) + a^2)^2}. \quad (47)$$

The mean curvature is given by:

$$H = \frac{eG - 2fF + gE}{2(EG - F^2)}. \quad (48)$$

After substitution, we obtain a new working formula for the mean curvature

13. When the surface actually becomes developable

For a truly developable surface, the following condition must be satisfied:

$$K = 0. \quad (50)$$

Thus, our spiral surface will be developable if

$$(2a^2 + r^2)r_{zz} - (a_z - r_z)^2 = 0. \quad (51)$$

this condition is imposed on the functions $a(z, t)$ and $\theta_0(z, t)$.

In general, an arbitrary surface of the form (12) is not necessarily strictly developable; it provides a convenient kinematic model of a spiral sheet. For exact developability, an additional constrain $K = 0$ must be imposed.

14. Normal to the cone surface

The cone is defined by

$$F_c(r, z) = r - r_c(z) = 0. \quad (52)$$

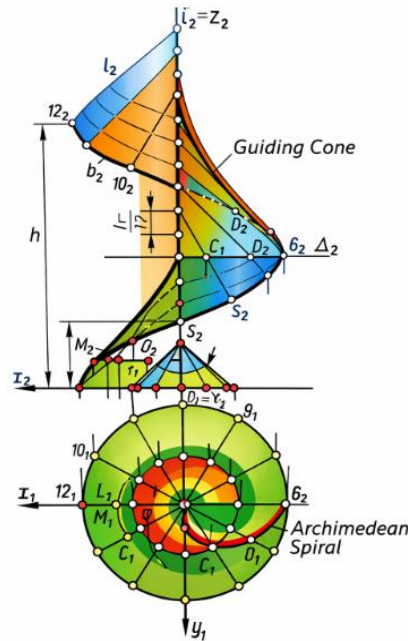


Fig. 1. This figure illustrates the geometric construction of a developable spiral surface obtained using a guiding cone.

In the cylindrical coordinate basis

$$\nabla F_c = \mathbf{e}_r - r'_c(z)\mathbf{e}_z = \mathbf{e}_r - \tan \alpha \mathbf{e}_z. \quad (53)$$

Unit normal to the cone surface:

$$\mathbf{n}_c = \frac{\mathbf{e}_r - \tan \alpha \mathbf{e}_z}{\sqrt{1 + \tan^2 \alpha}} = (\cos \alpha) \mathbf{e}_r - (\sin \alpha) \mathbf{e}_z. \quad (54)$$

In Cartesian coordinates $\mathbf{e}_r = (\cos \theta, \sin \theta, 0)$, thus

$$\mathbf{n}_c = \frac{(\cos \theta, \sin \theta, -\tan \alpha)}{\sqrt{1 + \tan^2 \alpha}}. \quad (55)$$

15. Condition for separation of the lifting vortex sheet from a cone

We consider two conditions characterizing this state.

1) Geometric Tangency Condition

While the layer remains attached to the cone, its base line satisfies $r = r_c(z)$ (56)

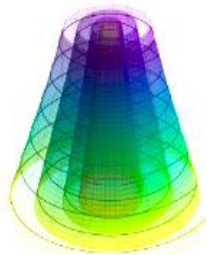


Fig. 2. A folded (streamlined) developable surface attached to the cone.

Thus, detachment occurs where the trajectory ceases to coincide with the cone surface.

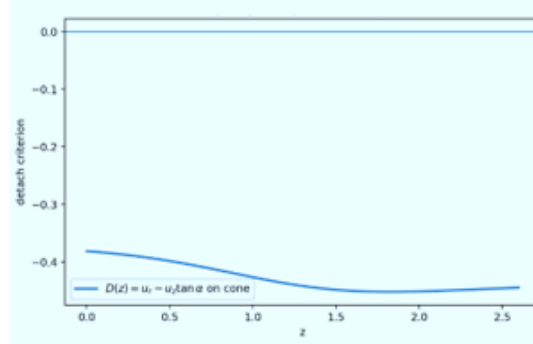


Fig. 3. The graph shows the dependence of the vortex-surface detachment criterion from the cone $D(z) = u_z - u_\theta \tan \alpha$, on the axial coordinate z .

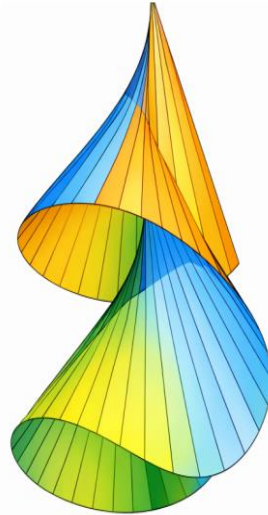


Fig. 4. The developable surface detached from the cone still retains the shape of the conical obstacle.

2) Kinematic No-Penetration Condition

On the cone, the following condition must hold:

$$\mathbf{v} \cdot \mathbf{n}_c = 0. \quad (57)$$

If we have

$$\mathbf{v} = u_r \mathbf{e}_r + u_\theta \mathbf{e}_\theta + u_z \mathbf{e}_z \quad (58)$$

since $\mathbf{e}_\theta \cdot \mathbf{n}_c = 0$,

$$u_r - u_z \tan \alpha = 0 \quad (59)$$

on the cone surface. This expresses the **condition** that the flow is **tangent** to the cone (see: Fig.1 and 2.).

16. Condition for the actual detachment of the lifting vortex sheet

If the layer detaches from the cone, it may be assumed that the velocity along the surface is no longer able to maintain the layer in contact with the cone. A simple model is

$$u_r - u_z \tan \alpha > 0 \quad (60)$$

where the flow deviates outward from the tangent to the cone. For an inviscid fluid, the shedding line is often defined through a critical value of the tangential shear:

$$\left. \frac{\partial u_t}{\partial n} \right|_{\text{cone}} = 0 \quad (61)$$

as an analogue of the separation condition, where u_e denotes the tangential velocity along the cone and n is the normal to it.

For an inviscid vortex model, it is more convenient to employ a pressure-based criterion along the cone: separation begins where the pressure gradient ceases to maintain the attachment of the layer:

$$\partial_s p = 0 \quad \text{or} \quad \partial_s p > 0 \quad (62)$$

depending on the chosen convention for the direction s .

17. Condition for the attachment of the surface to the cone along the shedding line

If $\mathbf{C}(s, t)$ is on the shedding line the following relation holds:

$$\mathbf{C}(s, t) \in \Sigma_c,$$

$$\mathbf{n}(\mathbf{C}) \cdot \mathbf{n}_c(\mathbf{C}) = 0 \quad \text{or} \quad \mathbf{d}(\mathbf{C}) \in T\Sigma_c$$

(63)

The formulation depends on whether the surface is specified through its normal vector or through its generating lines. In practice, geometric problems of surface dynamics of this type are more conveniently solved when the point of the shedding line lies on the cone, or when one of the tangent planes of the surface coincides with the tangent plane of the cone.

18. Conclusions

Thus, the proposed three-dimensional geometric model relates the shape of the developable spiral surface to several key parameters: the cone half-angle (α), the axial flow velocity $U(z, t)$, the angular velocity $\Omega(z, t)$, the shedding parameter μ , and the degree of fluid stratification.

The derived formulas make it possible to study the three-dimensional structure of unfolding vortex surfaces transporting matter that arise during the flow of swirling stratified fluids past cones, and can be used for further numerical modeling and stability analysis of such structures.

Interestingly, a similar method of constructing a developable surface can be observed when peeling an orange from top to bottom along a spiral. The resulting ‘cut and unfolded surface’ of the peel retains the ‘streamlined’ shape of the orange.

This paper extends the possibilities for studying the conditions of formation of secondary semi-inertial open vortex domains (recirculation regions arising under contact interactions) that develop inside the main closed spheroidal vortex, which rotates with a certain angular velocity that is considered transverse in this case. The vortex possesses its own internal core, while the general concept for constructing such interacting counter-vortex cones is described in detail in papers [1–3]. Such classes of vortices differ significantly from the tubular vortex models proposed by Helmholtz in 1858 [9].

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MEDICAL SCIENCES

THE INFLUENCE OF VITAMIN D STATUS ON COGNITIVE ABILITY IN PATIENTS WITH BIPOLAR DISORDER AND HEALTHY CONTROLS

Shkiryak A.

CEO and chief medical officer "Shkiryak Clinic"

Ukraine

Neurosurgeon

MD, MsSc

ORCID: <https://orcid.org/0000-0002-2282-8285>

Khanenko S.

"Shkiryak Clinic"

Ukraine

Family doctor

MD, MBA

ORCID: <https://orcid.org/0009-0000-4237-1158>

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Abstract

Recent evidence on the association between vitamin D and cognition in mentally healthy individuals is inconsistent. Furthermore, the link between vitamin D and cognitive ability in individuals with bipolar disorder has not been studied yet. Thus, we aimed to investigate the association between 25-hydroxyvitamin D (25(OH)D), 24,25 dihydroxyvitamin D (24,25(OH)₂D), the vitamin D metabolite ratio (VMR) and cognition in a cohort of euthymic patients with bipolar disorder. Vitamin D metabolites were measured simultaneously by liquid-chromatography tandem mass-spectrometry in serum samples from 86 outpatients with bipolar disorder and 93 healthy controls. Neither the inactive precursor 25(OH)D, nor the primary vitamin D catabolite 24,25(OH)₂D, or the vitamin D metabolite ratio were significantly associated with the domains "attention", "memory", or "executive function" in individuals with bipolar disorder and healthy controls. Further, no vitamin D deficiency effect or interaction group × vitamin D deficiency was found in the cognitive domain scores. In summary, the present study does not support vitamin D metabolism as a modulating factor of cognitive function in euthymic BD patients. Considering the current study's cross-sectional design, future research should expand these results in a longitudinal setting and include additional aspects of mental health, such as manic or depressive symptoms, long-term illness course and psychopharmacological treatment.

Keywords: bipolar disorder; vitamin D; functional vitamin D deficiency; 25(OH)D; 24,25(OH)₂D; VMR

Introduction

Bipolar disorder (BD) is a serious mental illness marked by pathological mood changes. Depressive and (hypo)manic, as well as euthymic phases occur at an unpredictable sequence. Lifetime prevalence ranges from 0.3–1.5% for bipolar type I disorder and up to 5.5% for bipolar type II disorder with a high heritability (1). Individuals who suffer from BD are often affected by impaired psychosocial functioning, cardiovascular and metabolic comorbidities, and earlier mortality. Importantly, many patients also exhibit cognitive deficits, which are associated with low everyday functioning (1).

In euthymic patients with BD, the largest effects on cognitive impairment are found in the domains of "memory", "attention", and "executive function" (2). Different sociodemographic, genetic, and clinical factors including psychotic symptoms (3), episode frequency (4,5), somatic conditions such as obesity (6) and metabolic syndrome (7), are assumed to contribute to cognitive deficits. In addition, lifestyle and nutrition can influence the illness course (8). Therefore, the potential role of vitamin D on cognition in mental disorders has gained significant interest in the recent past (9,10).

Vitamin D, which exists as skin-derived vitamin D₃ (cholecalciferol) and food-derived vitamin D₂ (ergocalciferol), is converted in the liver to 25-hydroxycholecalciferol (25(OH)D₃) and 25-hydroxyergocalciferol (25(OH)D₂), respectively. If not stated otherwise, laboratory tests for 25(OH)D capture both forms and thus report total 25(OH)D. Despite being the most abundant vitamin D metabolite in blood, 25(OH)D is still inactive and represents the body's vitamin D reservoir. Biologically active 1,25-dihydroxycholecalciferol (1,25(OH)₂D) is produced on demand via a second hydroxylation in position 1 that is catalyzed by 1 α -hydroxylase (CYP27B1). This primarily takes place within the kidneys, with fewer occurrences observed in various other tissues, such as the gut, breast, skeletal muscle, immune cells, and brain. Similar to the expression of 1 α -hydroxylase, the vitamin D receptor (VDR) is expressed in a broad range of tissues alluding to pleiotropic effects of vitamin D. In the brain, VDR has been detected in regions that are involved in cognitive processes (10). Excess amounts of 25(OH)D and 1,25(OH)₂D are eliminated by an additional hydroxylation in position 24. The resulting 24-hydroxylated metabolites are further processed and ultimately eliminated from the body. Overall, 24,25(OH)₂D is the most

abundant vitamin D catabolite that can be measured in blood (11).

Individuals with mental illnesses show a significant incidence of vitamin D deficiency (12,13). For example, Rihal et al. (14) illuminate the associations between vitamin D and schizophrenia, autism, depression, and ADHD. As a result, a deficiency in vitamin D could potentially emerge as a contributing factor to the onset of these neuropsychiatric disorders. Today, it is well accepted that the metabolic actions of vitamin D go far beyond calcium-phosphate homeostasis and involve the brain as well as many other tissues (15). In their extensive review, Cui et al. (16) provide a description of vitamin D in the central nervous system: Vitamin D supports myelination as well as functional recovery, and alterations in vitamin D levels within brain cells have been linked to a decrease in the density of nerve fibers, delayed and diminished development of dopamine neurons, and impaired release of gamma-aminobutyric acid and glutamate. Additionally, vitamin D is tied to the nerve growth factor, the restoration of dopamine levels, and stress responsiveness. Consequently, vitamin D can be regarded as a significant steroid in the physiology of brain neurons. Therefore, vitamin D contributes to mental health disorders and cognitive functions.

However, existing studies, which investigated potential associations between 25(OH)D and cognitive performance, show inconsistent results. Some studies indicate reduced cognitive performance in individuals with serum 25(OH)D concentrations below the recommended range (17,18), while others did not show any associations between those variables (19,20). One possible explanation for the inconsistent results is the variable analytical performance of widely used immunoassays for 25(OH)D, which lack sensitivity and specificity (21). Isotope dilution liquid chromatography tandem mass spectrometry (LC-MS/MS) is the preferred technique for the measurement of 25(OH)D and other related metabolites, which offers high sensitivity and specificity. Furthermore, LC-MS/MS enables the concurrent measurement of various vitamin D metabolites, offering dynamic insights into vitamin D metabolism (22). A recent study has shown that the parallel measurement of 25(OH)D and 24,25(OH)2D, and calculation of the vitamin D metabolite ratio (VMR), is more specific to establish functional vitamin D deficiency than the isolated measurement of the inactive prohormone 25(OH)D (23). Mayne et al. [9] provide an overview of the important roles that vitamin D plays in the body and brain, which are also related to cognitive functions. Among others, vitamin D is associated with a mechanism of synaptic plasticity (24). Synaptic plasticity describes the ability to form new synapses, thus representing a fundamental aspect in learning and memory (25).

Aim of the Study

Materials and Methods

Participants and study design

Individuals included in this study were participants of the longitudinal BIPLONG ("bipolar disorder in the long-term") cohort at the Division of Psychiatry

and Psychotherapeutic Medicine of the Medical University of Graz (Austria). BIPLONG aims to investigate the relationship between lifetime psychiatric history and different variables, such as biological parameters, brain function, and lifestyle in the long term. For a detailed description of the study design and other results, we refer to previous publications (7626).

BD was diagnosed by a psychiatrist or psychologist using the DSM-IV Structured Clinical Interview (27). BD I and BD II patients were included, but this distinction was not considered in further analyses. Exclusion criteria were neurodegenerative disorders, a premorbid IQ < 70 and the intake of vitamin D supplements. The present study only included data from euthymic patients with BD and mentally healthy controls without a history of a psychiatric disorder life-time and among first-degree relatives. Euthymia was verified by a Hamilton Depression Scale (HAMD; (28)) score of ≤ 9 and Young Mania Rating Scale (YMRS; (29)) score of ≤ 8 , which were rated by a psychiatrist or psychologist. Only euthymic patients were included to exclude possible effects caused by a manic or depressive episode, since Vrabie et al. (5) showed that patients in a manic episode have higher deficits in certain cognitive domains than depressive or euthymic patients. The study received approval from the ethics committee of the Medical University of Graz (EC-number: 25-335 ex 12/13).

From 635 participants of the BIPLONG study, 349 patients were diagnosed with BD. In total, 330 participants (180 patients with BD) were excluded due to missing vitamin D results. Further, information on current mood status was not available for 14 patients with BD, and 50 patients with BD were excluded because they had a YMRS score > 8 and/or a HAMD score > 9 and were therefore not considered euthymic. Cognitive data were missing for 57 participants (15 patients with BD). Four BD patients used vitamin D supplements. One healthy control participant was excluded due to impossible test values. Finally, 86 patients with BD (47 men, 39 women) and 93 healthy controls (29 men, 64 women) were included in the present study.

Determination of Vitamin D Metabolites

Fasting blood samples were collected for vitamin D testing and the measurement of numerous other blood biomarkers that are not subject of this study. Vitamin D status was assessed by measuring 25(OH)D and 24,25(OH)2D3 in serum. The results were used to calculate the VMR. Both vitamin D metabolites were measured simultaneously with a fully validated LC-MS/MS method that has performed satisfactorily for several years in the Vitamin D External Quality Assurance Scheme (DEQAS) and is regularly controlled by stringent internal quality control procedures. With the method used here, serum 25(OH)D represents the sum of 25(OH)D3 and 25(OH)D2, which are captured separately. Although both forms of 25(OH)D are catabolized by 24-hydroxylation, 25(OH)D2 normally accounts for 1–3% of the total 25(OH)D resulting in 24,25(OH)2D2 concentrations below the limit of quantitation. Therefore, vitamin D catabolism is assessed by 24,25(OH)2D3 as the only catabolite that is measurable with the method used here.

According to current recommendations from the Institute of Medicine (IOM), a 25(OH)D concentration < 50 nmol/L is considered deficient (30). Furthermore, functional vitamin D deficiency was diagnosed using a recently published approach from Herrmann (31). This approach requires a 24,25(OH)2D3 concentration < 3 nmol/L in combination with a VMR < 4%. Individuals that fulfilled only one of these criteria were classified as having a non-optimal vitamin D metabolism. For more details, see Zelzer et al. (22).

Assessment Scales

Cognitive performance of the participants was assessed using an extensive cognitive test battery that included the Trail Making Test Part A/B (32), the Color-Word Interference Test by J. R. Stroop (33), and the California Verbal Learning Test (CVLT; (34). All tests were provided in the German language. The raw scores were summed up to three cognitive domain scores: “attention”, “memory”, and “executive function”. For this purpose, the TMT-A (32) and the Color and Word part of the Stroop test (33) were combined into the domain score “attention”. The subscales of the CVLT (34) provided information about the domain score “memory”. The interference part of the Stroop test (33) as well as part B of the TMT (32) were used to measure “executive function”. Additionally, the premorbid IQ was measured with the Multiple-Choice Vocabulary Intelligence Test (MWT-B; (35)).

Statistics

Z-transformations were performed in order to sum up the cognitive raw scores to domain scores. Reaction times were inverted so that higher scores reflect higher performance in all domains. Since normal distribution was not given for the domain scores, a Rankit-transformation of these scores was performed.

Multiple hierarchical regression analyses were calculated to investigate whether 25(OH)D, 24,25(OH)2D3, or VMR were associated with the cog-

nition domain scores in BD patients and healthy controls. The independent variables were 25(OH)D, 24,25(OH)2D3, and VMR. Premorbid IQ and age were included as control variables. The following calculations were made to verify the prerequisites for conducting a multiple hierarchical regression analysis: Correlations and chi-square tests for linearity between independent and dependent variables, Durbin–Watson coefficients for autocorrelations, variance of inflation factors (VIF), tolerance values for multicollinearity, scatterplots for homoscedasticity of residuals, and the Shapiro–Wilk test for testing the normal distribution of the residuals. These prerequisites were met in all regression analyses.

To investigate if patients with BD versus healthy controls with or without functional vitamin D deficiency show a difference in the cognitive domain scores, a two-way multivariate analysis of covariance (MANCOVA) was calculated. For this purpose, the vitamin D catabolite 24,25(OH)2D3 and the VMR were considered together to classify the functional vitamin D deficiency. Premorbid IQ and age were included as covariables in the model. Skewness and kurtosis for normal distribution, Levene’s test for homogeneity, and graphs for linearity were calculated to verify the prerequisites of the MANCOVA. All prerequisites were met.

Results

Demographics and Sample Characteristics

The mean age of individuals with BD was 45.17 ± 13.15 years (min = 18 years, max = 72 years). The mean age of the healthy controls was 37.75 ± 15.32 years (min = 19 years, max = 76 years). Age, premorbid IQ, YMRS score, HAMD score, 25(OH)D, 24,25(OH)2D3, VMR, the cognitive domain scores, and the differences (as calculated by Mann–Whitney U-tests and chi-square tests) between patients with BD and the healthy controls can be seen in Table 1.

Table 1.

Sample characteristics and differences between patients with BD and healthy controls.

	Patients with BD (n = 86)	Healthy Controls (n = 93)	Differences
Age (Years), M ($\pm$ SD)	45.17 (13.15)	37.75 (15.33)	U = 2732.00 **, Z = -3.66
Sex (n, %)			
Male	47 (54.7%)	29 (31.2%)	$\chi^2 = 10.07$ *, $\phi = 0.24$
Female	39 (45.3%)	64 (68.8%)	
Premorbid IQ, M ($\pm$ SD)	109.51 (15.23)	112.18 (14.71)	U = 3579.50, Z = -1.22, p = 0.224
YMRS, M ($\pm$ SD)	0.93 (1.88)	0.12 (0.55)	U = 3082.50 **, Z = -4.13
HAMD, M ($\pm$ SD)	4.63 (3.45)	0.27 (0.95)	U = 902.50 **, Z = -9.78
Vitamin D variables, (n, %)			
25(OH)D, M ($\pm$ SD)	56.37 (23.64) nmol/L	57.29 (23.95) nmol/L	U = 3813.50, Z = -0.54
24,25(OH) ₂ D ₃ , M ($\pm$ SD)	3.59 (2.11) nmol/L	4.02 (2.51) nmol/L	U = 3608.50, Z = -1.13
VMR, M ($\pm$ SD)	6.31 (2.08) %	6.91 (2.51) %	U = 3465.00, Z = -1.54
25(OH)D			
<50 nmol/L	35 (40.7%)	34 (36.6%)	$\chi^2 = 0.32$, $\phi = 0.04$, p = 0.570
>50 nmol/L	51 (59.3%)	59 (63.4%)	
24,25(OH) ₂ D ₃			
<3 nmol/L	36 (41.9%)	31 (33.3%)	$\chi^2 = 1.39$, $\phi = 0.09$, p = 0.239
>3 nmol/L	50 (58.1%)	62 (66.7%)	
VMR (n, %)			
<4%	13 (15.1%)	13 (14.0%)	$\chi^2 = 0.05$, $\phi = 0.02$, p = 0.829
>4%	73 (84.9%)	80 (86.0%)	
Cognitive variables, M ($\pm$ SD)			

TMT-A (s)	35.21 (11.98)	26.04 (9.74)	U = 2082.50 **, Z = -5.53
TMT-B (s)	90.99 (51.14)	57.12 (20.96)	U = 2036.00 **, Z = -5.67
Stroop color word reading (s)	33.15 (7.06)	29.06 (4.63)	U = 2465.00 **, Z = -4.43
Stroop color naming (s)	51.70 (9.57)	44.11 (6.92)	U = 2051.00 **, Z = -5.62
Stroop interference (s)	85.16 (24.33)	67.67 (14.73)	U = 2054.00 **, Z = -5.62
CVLT trial 1-5	49.74 (13.26)	60.48 (11.80)	U = 2141.00 **, Z = -5.37
CVLT short delay free recall	10.02 (3.51)	12.82 (2.96)	U = 2090.00 **, Z = -5.54
CVLT short delay cued recall	11.03 (3.31)	13.27 (2.66)	U = 2363.00 **, Z = -4.76
CVLT long delay free recall	10.58 (3.57)	13.24 (3.09)	U = 2182.50 **, Z = -5.28
CVLT long delay cued recall	11.34 (3.29)	13.46 (2.91)	U = 2390.00 **, Z = -4.68

Multiple Hierarchical Regressions

Three multiple hierarchical regression analyses were calculated to investigate whether there is an association between 25(OH)D, 24,25(OH)2D as well as VMR with the three domain scores “attention”, “memory”, and “executive function” in individuals with BD and healthy controls. In the first model, age was included; in the second, age and premorbid IQ; in the third model, age, premorbid IQ, and 25(OH)D; in the fourth model, age, premorbid IQ, 25(OH)D, and 24,25(OH)2D3; and in the fifth model, all variables (age, premorbid IQ, 25(OH)D, 24,25(OH)2D3, and

VMR) were included. The order of entering the predictors was based on considerations of causal priority and served the purpose of controlling for potential effects.

Patients with Bipolar Disorder

Multiple hierarchical regression analysis revealed no significant association between the individual level of 25(OH)D 24,25(OH)2D3 or VMR and attention (Model 1: $F(1, 84) = 7.31$, $p = 0.008$; Model 2: $F(2, 83) = 4.82$, $p = 0.010$; Model 3: $F(3, 82) = 3.73$, $p = 0.014$; Model 4: $F(4, 81) = 3.28$, $p = 0.015$; Model 5: $F(5, 80) = 2.68$, $p = 0.027$). In all steps, only age showed a significant effect on attention. Table 2 shows the regression coefficients.

Table 2.

Association of age, premorbid IQ, 25(OH)D, 24,25(OH)₂D₃, VMR with “attention”, “memory”, and “executive function” in patients with BD.

		Attention					Memor		
		B	95%CI	β	t	p	B	95%CI	β
Model 1	Age	-0.02	[-0.04, -0.01]	-0.28	-2.70	0.008	-0.02	[-0.04, -0.01]	-0.30
Model 2	Age	-0.02	[-0.04, -0.01]	-0.32	-3.01	0.003	-0.03	[-0.04, -0.01]	-0.38
	Premorbid IQ	0.01	[-0.00, 0.02]	0.16	1.49	0.140	0.02	[0.01, 0.04]	0.33
Model 3	Age	-0.2	[-0.04, -0.01]	-0.31	-2.86	0.005	-0.03	[-0.04, -0.01]	-0.37
	Premorbid IQ	0.01	[-0.01, 0.02]	0.14	1.34	0.185	0.02	[0.01, 0.03]	0.32
	25(OH)D	-0.26	[-0.68, 0.16]	-0.13	-1.22	0.226	-0.19	[-0.59, 0.22]	-0.09
Model 4	Age	-0.02	[-0.04, -0.01]	-0.31	-2.91	0.005	-0.03	[-0.04, -0.01]	-0.37
	Premorbid IQ	0.01	[-0.01, 0.02]	0.13	1.15	0.252	0.02	[0.01, 0.04]	0.32
	25(OH)D	-0.05	[-0.57, 0.47]	-0.03	-0.20	0.841	-0.19	[-0.69, 0.31]	-0.09
	24,25(OH) ₂ D ₃	-0.35	[-0.87, 0.17]	-0.17	-1.35	0.181	0.01	[-0.50, 0.50]	0.01
Model 5	Age	-0.02	[-0.04, -0.01]	-0.31	-2.89	0.005	-0.03	[-0.04, -0.01]	-0.37
	Premorbid IQ	0.01	[-0.01, 0.02]	0.13	1.18	0.240	0.02	[0.01, 0.04]	0.33
	25(OH)D	-0.03	[-0.56, 0.49]	-0.02	-0.13	0.899	-0.16	[-0.67, 0.34]	-0.08
	24,25(OH) ₂ D ₃	-0.29	[-0.85, 0.27]	-0.14	-1.02	0.313	0.10	[-0.44, 0.64]	0.05
	VMR	-0.21	[-0.87, 0.46]	-0.08	-0.63	0.534	-0.29	[-0.93, 0.35]	-0.10

Memory

The results of the multiple hierarchical regression analysis indicated no significant association between 25(OH)D, 24,25(OH)₂D₃ or VMR and “memory”. In all steps (Model 1: $F(1, 84) = 8.03$, $p = 0.006$; Model 2: $F(2, 83) = 9.83$, $p < 0.001$; Model 3: $F(3, 82) = 6.82$, $p < 0.001$; Model 4: $F(4, 81) = 5.06$, $p = 0.001$; Model 5: $F(5, 80) = 4.20$, $p = 0.002$), age showed a significant effect on “memory”, as well as premorbid IQ once it was taken into the model (see Table 2).

Executive Function

In all steps of the multiple hierarchical regression analysis, age showed a significant effect on “executive function” (Model 1: $F(1, 84) = 11.48$, $p = 0.001$). Moreover, premorbid IQ showed a significant effect on “executive function” once it was taken into the model (Model 2: $F(2, 83) = 10.53$, $p < 0.001$; Model 3: $F(3, 82) = 7.01$, $p < 0.001$; Model 4: $F(4, 81) = 5.78$, $p < 0.001$; Model 5: $F(5, 80) = 4.83$, $p < 0.001$). No significant associations between 25(OH)D, 24,25(OH)₂D₃, or VMR and “executive function” were found (see Table 2).

Multivariate Analysis of Covariance

A MANCOVA was calculated to test for differences between patients with BD and the healthy controls (factor group) with functional vitamin D deficiency versus those without (factor vitamin D deficiency) in the cognitive domain scores “attention”, “memory”, and “executive function”. The covariates were the participants’ age and their premorbid IQ, which was calculated with the MWT-B (35). The descriptive results for vitamin D deficiency in both groups are listed in Table 3, showing that 43% of patients and 33.3% of controls were in the non-optimal group. MANCOVA showed a significant effect of group ($F(3171) = 2.67$, $p = 0.049$, $\eta^2 = 0.05$). The main effect for vitamin D deficiency ($F(3171) = 0.47$, $p =$

0.703 , $\eta^2 = 0.01$) and the interaction effect for group $\times$ vitamin D deficiency ($F(3171) = 0.99$, $p = 0.542$, $\eta^2 = 0.01$) were not significant. Age ($F(3171) = 24.23$, $p < 0.001$, $\eta^2 = 0.30$) and premorbid IQ ($F(3171) = 10.71$, $p < 0.001$, $\eta^2 = 0.16$) were significant covariates. Univariate post hoc analyses of variance (ANOVA) showed that BD patients exhibited lower performance in “memory” ($F(1173) = 4.63$, $p = 0.033$, $\eta^2 = 0.03$) and “executive function” ($F(1173) = 5.53$, $p = 0.020$, $\eta^2 = 0.03$) than the healthy controls. No difference between the two groups was found for the domain score attention ($F(1173) = 3.67$, $p = 0.057$, $\eta^2 = 0.21$).

Table 3.

Percentage of optimal and non-optimal functional vitamin D status in individuals with BD and healthy controls.

	Patients with BD (n = 86)	Healthy Controls (n = 93)	
Optimal	49 (57.0%)	62 (66.7%)	$\chi^2 = 1.78$, $\phi = 0.10$, $p = 0.182$
Non-optimal	37 (43.0%)	31 (33.3%)	

Discussion

The present study investigated whether the vitamin D status (25(OH)D), the main vitamin D catabolite (24,25(OH)2D3), or the vitamin D metabolite ratio (VMR) have an effect on cognition (divided into “attention”, “memory”, and “executive function”) in patients with BD. The findings do not substantiate a significant relationship between vitamin D metabolism and cognitive function. The different indices of vitamin D metabolism were not associated with “attention”, “memory”, or “executive function”, neither in BD patients nor in healthy controls. Our results are contrary to previous data, which showed reduced memory function in older individuals with low 24,25(OH)2D3 concentrations (36). Besides vitamin D, other factors that influence cognition may also be of interest. For example, associations between cognitive deficits and elevated triacylglycerol and glucose (37) or higher cytokine IL6 (38) have already been found. Other factors, such as the metabolic syndrome (7) anthropometric parameters also showed an association with cognition in patients with BD. Recent research emphasizes the importance of utilizing vitamin D metabolites to determine the vitamin D status, especially to detect deficiency (11,22).

In addition, the occurrence of functional vitamin D deficiency was comparable in BD patients and healthy controls. Therefore, 24,25(OH)2D3 and VMR

were used to determine functional vitamin D deficiency. However, no functional vitamin D deficiency effect could be found in our analyses, which tested differences in cognitive domain scores between patients with BD and the healthy controls. In concordance with the current literature, we found that individuals with BD showed poorer memory and executive function performance than the healthy controls. Our findings align with prior research, in which patients with BD also showed cognitive deficits in memory (2), executive function and processing speed (3).

The inconsistent results could be, at least partially, explained by the substantially different age of the participants. In BIPLONG, the participants were rather young, which limits the chance for significant effects induced by vitamin D deficiency. The absence of an association between vitamin D and the domain scores “attention”, “memory”, and “executive function” argues against vitamin D deficiency as a promotor of cognitive dysfunction in BD. This is an important finding since BD patients are often severely impaired by cognitive and somatic deficits. Further possible reasons for inconsistent results regarding an association between BD and poorer cognitive performance could be the use of different cognitive tests or different assignments of these tests to the cognitive domain scores.

A particular strength of our study is the measurement of 25(OH), 24,25(OH)2D3 and VMR, which pro-

vides a more comprehensive insight into vitamin D metabolism (11, 22). Determining 24,25(OH)₂D₃ and VMR offers important metabolic information beyond the sole measurement of 25(OH)D. Functional vitamin D deficiency was equally prevalent in BD patients and in the healthy controls, which argues against a significant role of vitamin D for cognition. However, mean 25(OH)D concentrations of 56.37 nmol/L and 57.29 nmol/L were found in BD patients and the controls, respectively, suggesting a relatively adequate vitamin D supply, which limits the margin for significant effects. In contrast to the present study, previous investigations mainly included hospitalized patients with severe symptoms, in whom 25(OH)D concentrations are typically lower (4). Existing evidence (4) suggests that BD patients with more frequent manic episodes perform worse on the CVLT than those with less frequent manic episodes. This is an important aspect as manic patients are more often affected by worse memory and executive function compared to depressed and euthymic patients. Therefore, it remains plausible that there is a connection between vitamin D and cognition in symptomatic BD patients. Furthermore, it could be theorized that vitamin D supplementation might have positive effects on mood in BD patients that are mediated via the serotonergic pathway (39). This hypothesis finds support in data from healthy individuals, which demonstrate a beneficial impact of vitamin D supplementation on mood (39). However, in a recent literature review, Huiberts et al. (40) concluded that the existing data are inconsistent.

Limitation of the Study

Our study possesses various strengths and limitations that warrant attention when interpreting the findings. The simultaneous determination of 25(OH)D, 24,25(OH)₂D₃ and VMR provides important metabolic information that extends beyond the evaluation of vitamin D stores by only measuring 25(OH)D. These parameters offered the possibility to establish functional vitamin D deficiency, which has been linked to adverse clinical outcomes (31). Furthermore, the use of a validated state of the art LC-MS/MS method ensured accurate results that are not affected by the analytical limitations of commonly used 25(OH)D immunoassays (21). Another advantage of this study is a rather large cohort of euthymic BD patients in whom the diagnosis of BD was thoroughly established and cognition was assessed by a well-elaborated cognitive test battery. However, when considering the potential impacts of vitamin D on sleep and mood, significant associations between vitamin D and cognition in manic or depressive BD patients cannot be excluded. Also, many participants were treated with psychopharmacological medication so that potential drug effects on vitamin D metabolism and cognitive function cannot be ruled out. Notably, patients with BD were taking different medications, making it difficult to identify the different effects of each medication. Previous studies reported heterogeneous cognitive effects of commonly used medications in BD patients (41,42). For example, Paterson et al. (41) found no effect of lithium on attention, but a positive effect on psychomotor speed in patients with

BD, whereas Holmes et al. (42) reported a negative effect on attention and affective processing. Factors such as medications, organic diseases, diet, and sun exposure are potential confounders of vitamin D metabolite concentrations, and the absence of this information weakens the statistical power of the present study. However, to reduce confounding factors, we excluded subjects with vitamin D supplementation. In addition, the known seasonal variations of 25(OH)D were accounted for by distributing the study dates relatively evenly throughout the year. Furthermore, the sex-specific differences in the concentration of vitamin D in patients with severe mental illness could be relevant to explore the potentially sex-specific involvement of vitamin D in the pathogenesis of mental health disorders. Previous research suggests a female-specific involvement of vitamin D in the pathogenesis of depression, relating vitamin D to the production/release of gonadal hormones (43,44). This view has been supported by previous research providing evidence that the gender difference in the prevalence of depression is less evident during menopause, when gonadal hormonal flux stabilizes (45).

Another aspect to consider is the unknown duration of vitamin D deficiency that may vary between the study participants. When taking into account that vitamin D deficiency has potential adverse effects on the signaling pathways in the brain, a longer duration of vitamin D deficiency could potentially be more relevant for cognition than short-lasting deficiencies. As vitamin D₃ production is also subject to pronounced seasonal variation, the time of blood collection may also be a factor (46). Finally, this study included only euthymic patients so that potential effects of manic or depressive symptoms could not be assessed. Ultimately, this study is a cross-sectional study, which means that causal relationships cannot be assessed.

Further studies, ideally of a prospective nature, are needed to consolidate the present results. Such studies should include symptomatic and asymptomatic patients to reveal possible effects released by a manic or depressive episode. In addition, it cannot be excluded that vitamin D influences cognition indirectly through the modulatory effects of other metabolic pathways and inflammatory processes.

Conclusions

In summary, the present study does not support vitamin D metabolism as a modulating factor of cognitive function in euthymic BD patients. Moreover, the incidence of low vitamin D stores and functional vitamin D deficiency did not significantly differ between BD patients and healthy controls. As this is the first study that addressed the impact of vitamin D on cognitive function in BD patients, more research is needed to expand the present findings. Specifically, longitudinal studies that include euthymic and symptomatic BD patients are of particular interest.

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VITAMIN D AND THE RISK OF DEMENTIA AND ALZHEIMER DISEASE


 RESTRICTED
Shkiryak A.*CEO and chief medical officer "Shkiryak Clinic"**Ukraine**Neurosurgeon**MD, MsSc*ORCID: <https://orcid.org/0000-0002-2282-8285>**Khanenko S.***"Shkiryak Clinic"**Ukraine**Family doctor**MD, MBA*ORCID: <https://orcid.org/0009-0000-4237-1158><https://doi.org/10.5281/zenodo.19050746>**Abstract****Objective:**

To determine whether low vitamin D concentrations are associated with an increased risk of incident all-cause dementia and Alzheimer disease.

Methods:

One thousand six hundred fifty-eight elderly ambulatory adults free from dementia, cardiovascular disease, and stroke who participated in the US population-based Cardiovascular Health Study between 1992–1993 and 1999 were included. Serum 25-hydroxyvitamin D (25(OH)D) concentrations were determined by liquid chromatography-tandem mass spectrometry from blood samples collected in 1992–1993. Incident all-cause dementia and Alzheimer disease status were assessed during follow-up using National Institute of Neurological and Communicative Disorders and Stroke/Alzheimer's Disease and Related Disorders Association criteria.

Results:

During a mean follow-up of 5.6 years, 171 participants developed all-cause dementia, including 102 cases of Alzheimer disease. Using Cox proportional hazards models, the multivariate adjusted hazard ratios (95% confidence interval [CI]) for incident all-cause dementia in participants who were severely 25(OH)D deficient (<25 nmol/L) and deficient (≥ 25 to <50 nmol/L) were 2.25 (95% CI: 1.23–4.13) and 1.53 (95% CI: 1.06–2.21) compared to participants with sufficient concentrations (≥ 50 nmol/L). The multivariate adjusted hazard ratios for incident Alzheimer disease in participants who were severely 25(OH)D deficient and deficient compared to participants with sufficient concentrations were 2.22 (95% CI: 1.02–4.83) and 1.69 (95% CI: 1.06–2.69). In multivariate adjusted penalized smoothing spline plots, the risk of all-cause dementia and Alzheimer disease markedly increased below a threshold of 50 nmol/L.

Conclusion:

Our results confirm that vitamin D deficiency is associated with a substantially increased risk of all-cause dementia and Alzheimer disease. This adds to the ongoing debate about the role of vitamin D in nonskeletal conditions.

Introduction

Recent meta-analyses confirm that low serum vitamin D concentrations are associated with prevalent Alzheimer disease (AD) dementia and cognitive impairment. (1-3) This is cause for concern given the high rates of vitamin D deficiency in older adults (4) and continued uncertainty about the causes of AD and other forms of dementia. (5) Both the 1,25-dihydroxyvitamin D3 receptor and 1 α -hydroxylase, the enzyme responsible for synthesizing the bioactive form of vitamin D, are found throughout the human brain. (6) In vitro, vitamin D increases the phagocytic clearance of amyloid plaques by stimulating macrophages (7,8) and reduces amyloid-induced cytotoxicity and apoptosis in primary cortical neurons. (9) Vitamin D deficiency has also been linked to vascular dysfunction and ischemic stroke risk (10) as well as brain atrophy. (11) However, reverse causation is also possible, as the onset of dementia may lead to dietary changes and reduced outdoor activity, which in turn result in lower vitamin D concentrations. (12)

Previous prospective studies have established that low vitamin D concentrations in elderly adults are associated with an increased risk of cognitive decline. (3,13-15) Furthermore, it has been hypothesized that the risk of cognitive decline markedly increases below a threshold between 25 and 50 nmol/L. (12) However, preliminary prospective studies of vitamin D and dementia risk have been discordant. In a small study of 40 high-functioning elderly women, severe vitamin D deficiency (<25 nmol/L) was associated with a higher risk of non-AD dementias but not AD over 7 years. (16) In contrast, in 10,186 individuals, severe vitamin D deficiency was associated with medical records indicating AD but not vascular dementia over 30 years of follow-up. (17) The discrepancy in these findings may be due to a lack of statistical power (16) or use of unstandardized dementia diagnoses from medical records, which may result in considerable misclassification. (17) We therefore conducted what is to our knowledge the first large, prospective, population-based study incorporating a comprehensive adjudicated assessment of

dementia and AD to examine their relationship with vitamin D concentrations.

METHODS

Participants

Participants were selected from the Cardiovascular Health Study (CHS), a large, prospective, population-based study in the United States designed to investigate the underlying causes of cardiovascular disease in older men and women. (18) The CHS recruited participants from 4 communities: Forsyth county, NC (36.1° north, 80.3° west); Sacramento county, CA (38.5° north, 121.4° west); Washington county, MD (39.6° north, 77.8° west); and Pittsburgh, PA (40.4° north, 80.0° west). The cohort consisted of 5,201 adults recruited in 1989–1990 and an additional 687 African-American participants recruited in 1992–1993. Of these 5,888 participants, 4,692 ambulatory participants had complete exam data in 1992–1993 (the baseline assessment for the current study). Serum 25-hydroxyvitamin D (25(OH)D) concentrations were not measured in 1,424 participants who had prevalent cardiovascular disease or stroke (one or more of the following: coronary heart disease, congestive heart failure, claudication, atrial fibrillation, pacemaker, implantable cardioverter defibrillator, stroke, or TIA), determined by medical records, ECG findings, and self-report. (19) Further exclusions were insufficient serum volumes for vitamin D assay to be performed (<500 µL; $n = 945$) and missing adjudicated dementia status ($n = 596$). (20) Participants with prevalent dementia at the time of the vitamin D collection ($n = 69$) were excluded from the main analyses but included in secondary analyses of prevalent dementia. This resulted in a final sample of 1,658 participants for the main prospective analyses and 1,727 participants for the secondary baseline analyses. Those lost to follow-up (defined as participants with serum 25(OH)D measured but no diagnostic assessment of incident dementia) were older (mean [SD], 74.3 [5.4] years vs 73.8 [4.6] years, $p = 0.03$), were more likely to be nonwhite (20.0% vs 13.1%, $p < 0.001$), and had lower serum 25(OH)D concentrations (mean [SD], 61.2 [39.4] nmol/L vs 64.4 [26.5] nmol/L, $p = 0.03$), but they were no more likely to be female (71.4% vs 69.2%, $p = 0.31$) or less educated (27.4% vs 23.4% did not finish high school, 53% vs 54% finished high school/some college/vocational qualifications, and 19.6% vs 22.6% completed college or professional qualifications, $p = 0.10$).

Standard protocol approvals, registrations, and patient consents

The institutional review boards at each participating institution approved the research protocols, and all participants provided written informed consent.

Serum 25(OH)D measurement

Serum samples collected in 1992–1993 were stored at -70°C at the Laboratory for Clinical Biochemistry Research at the University of Vermont, and measurements were performed by the University of Washington Clinical Nutrition Research Unit in 2008. (21) Total 25(OH)D (the sum of 25(OH)D₂ and 25(OH)D₃) was measured using liquid chromatography-tandem mass spectrometry (LC-MS) on a Waters Quattro micro mass spectrometer (Waters, Milford,

MA); the interassay coefficient of variation was <3.4%. (19) Calibration of serum 25(OH)D concentrations was verified using SRM 972 from the National Institute of Standards and Technology. (22)

Diagnosis of all-cause dementia and AD

Dementia and AD status was assessed in 1998–1999 by a committee of neurologists and psychiatrists on the basis of annual cognitive assessments, repeat MRI scans, medical records, questionnaires, and proxy interviews. Diagnosis of dementia was based on a progressive or static cognitive deficit with impairment in at least 2 cognitive domains and a history of normal cognitive function before the onset of abnormalities. Incident all-cause dementia and AD were diagnosed according to the National Institute of Neurological and Communicative Disorders and Stroke/Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria. Further details can be found elsewhere. (23)

Covariates

We adjusted for covariates identified as potential confounders (1–3, 12): age in years, season of blood collection (December–February, March–May, June–August, September–November), education status (did not finish high school, finished high school/some college/vocational qualifications, completed college/professional qualifications), sex, body mass index (BMI in kg/m²), smoking (nonsmoker, current smoker), alcohol consumption (National Institute on Alcohol Abuse and Alcoholism definitions: nondrinkers, moderate drinkers [women ≤ 7 drinks/week; men ≤ 14 drinks/week], heavy drinkers [women > 7 drinks/week; men > 14 drinks/week]), and significant depressive symptoms (score ≥ 8 on the revised 10-item Center for Epidemiologic Studies Depression Scale (24)).

Statistical analysis

Cox proportional hazards models were used to assess the associations between baseline serum 25(OH)D and the risk of incident all-cause dementia and AD. Participants were considered at risk for dementia from baseline (1992–1993) and were censored at death or the end of follow-up in June 1999. All-cause dementia included AD cases, and analyses for AD were censored for non-AD dementia. The proportionality of hazards assumption was assessed using the Schoenfeld residuals technique. (25) We analyzed serum 25(OH)D using clinically relevant cutpoints: <25 nmol/L (severely deficient), ≥ 25 nmol/L to <50 nmol/L (deficient), and ≥ 50 nmol/L (sufficient). (26) Linear trends across categories were tested by entering 25(OH)D groups into models as a continuous rather than a categorical variable. In basic adjusted models, we controlled for age and season of blood collection. In fully adjusted models, we controlled for education, sex, BMI, smoking, alcohol consumption, and depressive symptoms. To investigate any threshold, we used multivariate adjusted penalized smoothing spline plots. Eight outlying participants with 25(OH)D concentrations between 170 and 283 nmol/L were excluded due to imprecision at the extreme end of the distribution (none developed dementia during follow-up).

In secondary analyses, serum 25(OH)D concentrations were analyzed as a continuous rather than a categorical variable. 25(OH)D concentrations were standardized to have a mean of 0 and an SD of 1 to aid interpretation. Because 25(OH)D concentrations were positively skewed, they were normalized using a log transformation. We repeated the main analyses to include adjustments for health conditions that have been identified as potential mediators for the association between serum 25(OH)D concentrations and dementia risk^{12,13}: diabetes (American Diabetes Association guidelines: using oral hypoglycemic agents or insulin, or plasma fasting glucose ≥ 7.0 mmol/L) and/or hypertension (3 categories; no hypertension: systolic < 140 mm Hg and diastolic < 90 mm Hg; treated hypertension: hypertensive medication; untreated hypertension: systolic ≥ 140 mm Hg or diastolic ≥ 90 mm Hg with no hypertensive medication). We also adjusted for ethnicity (white/black) and examined potential interactions with ethnicity in separate models, although it is recognized that this may represent overadjustment.²⁷ In a further analysis, we adjusted for socioeconomic status indicators: annual income ($< \$12,000$, $\$12,000$ – $24,999$, $\$25,000$ – $49,999$, $\geq \$50,000$, missing) and usual lifetime occupation (professional/technical/managerial/administrative, sales/clerical service, craftsman/machine operator/laborer/farming/forestry, housewife, other/missing). Multivariate adjusted logistic regression models were used to investigate the cross-sectional association between serum 25(OH)D and prevalent all-cause dementia ($n = 69$) and AD ($n = 34$).

In sensitivity analyses, we excluded participants who developed all-cause dementia ($n = 12$) and AD ($n = 6$) within 1 year of baseline to remove the possibility

that any association observed was determined by these “early converters.” *p* Values were 2-sided throughout, and the type I error rate for statistical significance was set at 0.05. Analyses were performed using Stata SE version 12 (StataCorp, College Station, TX) with the exception of the spline plots, which were fitted in R version 2.15.1 (www.r-project.org).

RESULTS

Table 1 displays baseline characteristics for the study population included in the main prospective analyses. Participants were followed up for a mean of 5.6 years (SD 1.6, median 6.1, range 0.1–8.4). During 9,317.5 person-years of follow-up, 171 participants developed all-cause dementia and 102 developed AD. The risk of developing both all-cause dementia and AD was significantly higher in participants who were either 25(OH)D deficient or severely deficient (table 2). In minimally adjusted models, those who were deficient had about a 51% increased risk of all-cause dementia, whereas the increased risk for those who were severely deficient was about 122%. The strength of the association observed for incident AD was similar to that observed for all-cause dementia. Additional adjustment for potential confounders did not alter the pattern of results, and there was a linear trend across groups in all analyses, suggesting a monotonic association. Kaplan-Meier plots for unadjusted rates of incident all-cause dementia and AD show clear differences in risk by 25(OH)D concentrations after 2–3 years of follow-up (figure 1). Multivariate adjusted smoothing spline plots suggest that the risk of all-cause dementia and AD markedly increases at 25(OH)D concentrations below 50 nmol/L (figure 2).

Table 1.

Baseline characteristics of 1,658 CHS participants by serum 25(OH)D concentration

Table 1 Baseline characteristics of 1,658 CHS participants by serum 25(OH)D concentration				
Characteristic	Serum 25(OH)D, nmol/L			
	All (n = 1,658)	≥50 (n = 1,169)	≥25 to <50 (n = 419)	<25 (n = 70)
Age, y, mean (SD)	73.6 (4.5)	73.6 (4.4)	73.7 (4.6)	74.1 (5.1)
Season tested, n (%)				
December–February	363 (21.9)	207 (17.7)	133 (31.7)	23 (32.9)
March–May	383 (23.1)	207 (17.7)	144 (34.4)	32 (45.7)
June–August	475 (28.7)	407 (34.8)	60 (14.3)	8 (11.4)
September–November	437 (26.4)	348 (29.8)	82 (19.6)	7 (10.0)
Education (n = 1,655), n (%)				
Did not finish high school	366 (22.1)	243 (20.8)	103 (24.7)	20 (28.6)
Finished high school/some college/vocational	910 (55.0)	644 (55.1)	226 (54.2)	40 (57.1)
College/professional	379 (22.9)	281 (24.1)	88 (21.1)	10 (14.3)
Female, n (%)	1,148 (69.2)	756 (64.7)	330 (78.8)	62 (88.6)
BMI, kg/m ² , mean (SD)	26.5 (4.5)	26.1 (4.2)	27.7 (5.1)	27.4 (5.3)
Current smoker (n = 1,615), n (%)	149 (9.2)	93 (8.2)	46 (11.2)	10 (14.7)
Alcohol use (n = 1,656), n (%) ^a				
Nondrinkers	898 (54.2)	613 (52.4)	245 (58.6)	40 (58.0)
Moderate drinkers	621 (37.5)	452 (38.7)	145 (34.7)	24 (34.8)
Heavy drinkers	137 (8.3)	104 (8.9)	28 (6.7)	5 (7.3)
Depressive symptoms (CES-D score ≥8), n (%)	359 (21.7)	221 (18.9)	117 (27.9)	21 (30.0)

Diabetes, n (%) ^b	175 (10.6)	95 (8.1)	64 (15.3)	16 (22.9)
Hypertension, n (%)				
Normal	696 (42.0)	526 (45.0)	151 (36.0)	19 (27.1)
Treated	639 (38.5)	412 (35.2)	189 (45.1)	38 (54.3)
Untreated	323 (19.5)	231 (19.8)	79 (18.9)	13 (18.6)
Years of follow-up, mean (SD)	5.6 (1.6)	5.8 (1.5)	5.3 (1.8)	5.2 (1.6)
White, n (%)	1,452 (87.6)	1,088 (93.1)	322 (76.9)	42 (60.0)
Income, \$, n (%)				
<12,000	330 (19.9)	198 (16.9)	107 (25.5)	25 (35.7)
12,000–24,999	547 (33.0)	394 (33.7)	131 (31.3)	22 (31.4)
25,000–49,999	449 (27.1)	343 (29.3)	95 (22.7)	11 (15.7)
≥50,000	234 (14.1)	179 (15.3)	49 (11.7)	6 (8.6)
Missing	98 (5.9)	55 (4.7)	37 (8.8)	6 (8.6)
Occupation, n (%)				
Professional/technical/managerial/administrative	611 (36.9)	452 (38.7)	135 (32.2)	24 (34.3)
Sales/clerical service	254 (15.3)	176 (15.1)	69 (16.5)	9 (12.9)
Craftsman/machine operator/laborer/farming/forestry	219 (13.2)	159 (13.6)	47 (11.2)	13 (18.6)
Housewife	430 (25.9)	277 (23.7)	134 (32.0)	19 (27.1)
Other/missing	144 (8.7)	105 (9.0)	34 (8.1)	5 (7.1)

Abbreviations: 25(OH)D = 25-hydroxyvitamin D; BMI = body mass index; CES-D = Center for Epidemiologic Studies Depression Scale²⁴ (revised 10-item scale); CHS = Cardiovascular Health Study.

^a National Institute on Alcohol Abuse and Alcoholism guidelines.

^b American Diabetes Association guidelines.

Table 2.

Cox proportional hazards regression models of incident all-cause dementia and Alzheimer disease by serum 25(OH)D concentration

Table 2 Cox proportional hazards regression models of incident all-cause dementia and Alzheimer disease by serum 25(OH)D concentration						
Dementia status	No. of participants	No. of cases	Serum 25(OH)D, nmol/L			p Value for linear trend
			≥50	≥25 to <50, HR (95% CI)	<25, HR (95% CI)	
All-cause dementia						
Model A ^a	1,658	171	1 (reference)	1.51 (1.06-2.16)	2.22 (1.23-4.02)	0.002
Model B ^b	1,615	168	1 (reference)	1.53 (1.06-2.21)	2.25 (1.23-4.13)	0.002
Alzheimer disease						
Model A ^a	1,589	102	1 (reference)	1.67 (1.06-2.62)	2.27 (1.06-4.84)	0.006
Model B ^b	1,547	100	1 (reference)	1.69 (1.06-2.69)	2.22 (1.02-4.83)	0.008

Abbreviations: 25(OH)D = 25-hydroxyvitamin D; CI = confidence interval; HR = hazard ratio.

^a Adjusted for age and season of vitamin D collection.

^b Adjusted for model A and education, sex, BMI, smoking, alcohol consumption, and depressive symptoms.

Figure 1. Kaplan-Meier curves for unadjusted rates of all-cause dementia and Alzheimer disease by serum 25-hydroxyvitamin D (25(OH)D) concentrations.

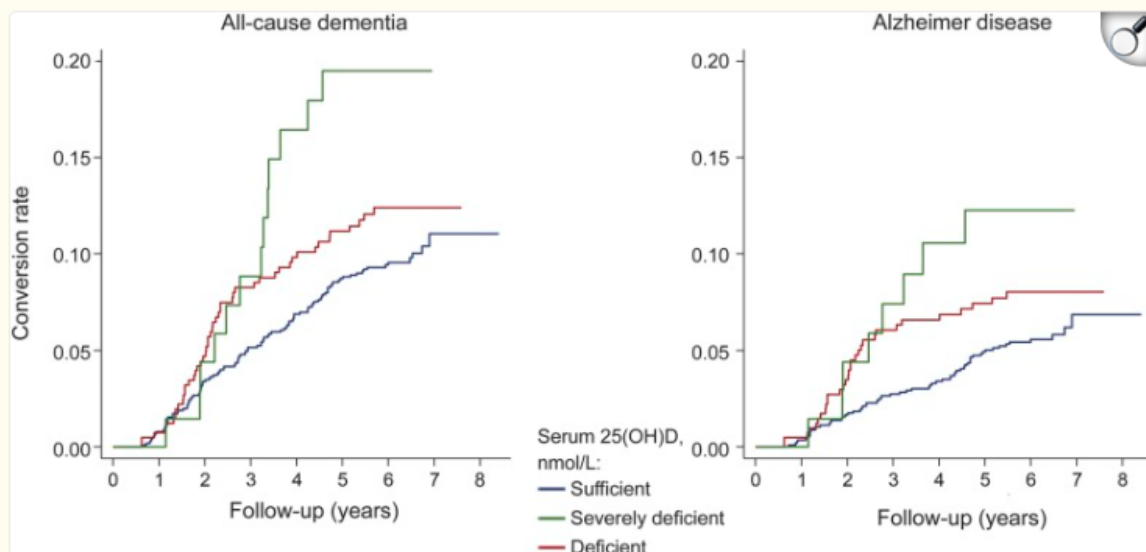
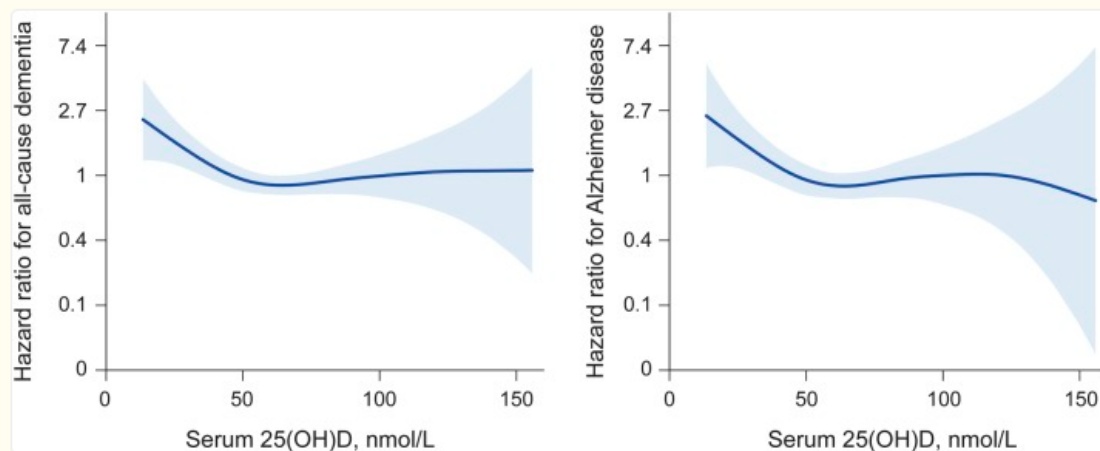


Figure 2. Multivariate adjusted smoothing spline plots showing the hazard ratios for dementia and Alzheimer disease by serum 25(OH)D concentrations.



Secondary analyses incorporating continuous 25(OH)D concentrations gave a similar pattern of results. The multivariate adjusted risks for incident all-cause dementia and incident AD reduced by 18% (hazard ratio [HR] = 0.82, 95% confidence interval [CI]: 0.70–0.97, $p = 0.02$) and 20% (HR = 0.80, 95% CI: 0.65–0.99, $p = 0.04$), respectively, for each 1 SD increase in log-transformed 25(OH)D. Additional adjustment for diabetes or hypertension did not change the pattern of results for either incident all-cause dementia or AD, suggesting that these conditions are unlikely to mediate the observed associations (table 3). Adjustment for ethnicity attenuated the main results slightly but did not change the overall pattern of results, and there were no significant interactions (table e-1 on the *Neurology*® Web site at Neurology.org). Additional adjustment for income and occupation did not

change the associations either (table e-2). The odds of prevalent all-cause dementia and AD at baseline in participants who were severely 25(OH)D deficient were 3–6 times higher than those with sufficient 25(OH)D, with a linear trend across groups (table e-3). After excluding participants who developed all-cause dementia and AD within 1 year of baseline, the multivariate adjusted HRs in participants who were severely 25(OH)D deficient and deficient compared to participants with sufficient 25(OH)D concentrations were 2.42 (95% CI: 1.33–4.39) and 1.54 (95% CI: 1.06–2.28) for incident all-cause dementia (p for linear trend = 0.001) and 2.36 (95% CI: 1.08–5.16) and 1.69 (95% CI: 1.04–2.73) for AD (p for linear trend = 0.007). This suggests that the association is not driven by “early converters.”

Table 3.

Cox proportional hazards regression models of incident all-cause dementia and Alzheimer disease by serum 25(OH)D concentration with additional adjustment for potential mediators

Table 3 Cox proportional hazards regression models of incident all-cause dementia and Alzheimer disease by serum 25(OH)D concentration with additional adjustment for potential mediators						
Dementia status ^a	No. of Participants	No. of cases	Serum 25(OH)D, nmol/L			p Value for linear trend
			≥50	≥25 to <50, HR (95% CI)	<25, HR (95% CI)	
All-cause dementia						
Diabetes	1,615	168	1 (reference)	1.50 (1.04-2.17)	2.18 (1.18-4.01)	0.003
Hypertension	1,615	168	1 (reference)	1.52 (1.05-2.20)	2.24 (1.22-4.12)	0.002
Diabetes and hypertension	1,615	168	1 (reference)	1.50 (1.04-2.17)	2.18 (1.18-4.02)	0.003
Alzheimer disease						
Diabetes	1,547	100	1 (reference)	1.65 (1.03-2.63)	2.14 (0.98-4.68)	0.01
Hypertension	1,547	100	1 (reference)	1.69 (1.05-2.69)	2.26 (1.04-4.90)	0.008
Diabetes and hypertension	1,547	100	1 (reference)	1.65 (1.03-2.65)	2.20 (1.01-4.80)	0.01

Abbreviations: 25(OH)D = 25-hydroxyvitamin D; BMI = body mass index; CI = confidence interval; HR = hazard ratio.

^a Models also adjusted for age, season of vitamin D collection, education, sex, BMI, smoking, alcohol consumption, and depressive symptoms.

Abbreviations: 25(OH)D = 25-hydroxyvitamin D; BMI = body mass index; CI = confidence interval; HR = hazard ratio.

^a Models also adjusted for age, season of vitamin D collection, education, sex, BMI, smoking, alcohol consumption, and depressive symptoms.

DISCUSSION

We have conducted what is to our knowledge the first large, prospective, population-based study to examine vitamin D concentrations in relation to a comprehensive adjudicated assessment of dementia and AD. We observed a strong monotonic association between 25(OH)D concentrations and the risk of both incident all-cause dementia and AD. This association was robust to adjustment for a range of potential confounders and the exclusion of dementia cases that occurred within a year of baseline.

The 2 previous studies that have investigated vitamin D and incident dementia have produced conflicting results. The first found that severe vitamin D deficiency was associated with non-AD dementia but not AD risk.¹⁶ The second found that severe vitamin D deficiency was associated with AD but not vascular dementia risk.¹⁷ However, the first study incorporated a small sample of high-functioning women ($n = 40$), and the lack of association with AD may reflect limited statistical power. The second study relied on registry data for dementia diagnoses, which may have resulted in considerable misclassification. Our results establish that low 25(OH)D concentrations are linked to an increased risk of incident all-cause dementia and AD, and they are consistent with studies suggesting a link with cognitive impairment (1,3,12,26,28) and cognitive decline. (13-15) Few studies have examined potential mediators of this association, although there was no evidence in the present study or the InCHIANTI (13) study for mediation by diabetes or hypertension.

A threshold below which the risk of dementia increases markedly has previously been hypothesized to lie in the 25–50 nmol/L range. (12) The optimal level of vitamin D for general health remains controversial, with the Institute of Medicine recommending 50 nmol/L and the Endocrine Society recommending 75 nmol/L. (29,30) A post hoc analysis of the Women's

Health Initiative randomized controlled trial discovered that a relatively low dose of vitamin D (400 IU) in combination with calcium (1,000 mg) did not protect against dementia over a mean follow-up period of 7.8 years in women who had relatively high serum vitamin D levels at baseline (mean of 49 nmol/L in a small subsample). (31) Our results clarify that the threshold above which older adults are unlikely to benefit from supplementation with regard to dementia risk is likely to lie in the region of 50 nmol/L when 25(OH)D concentrations are measured using LC-MS. This therefore adds to the ongoing debate regarding optimal vitamin D levels for different health outcomes.

A number of potential mechanisms linking low vitamin D levels with the risk of dementia have been identified. (32) Vitamin D receptors are expressed throughout the brain, including areas involved in memory such as the hippocampus and dentate gyrus. (6) Similarly, the enzyme that synthesizes the active form of vitamin D, 1 α -hydroxylase, is produced in several cerebral regions. The active form of vitamin D, 1,25dihydroxy-vitamin D3 (1,25-D3), regulates neurotrophin expression, such as nerve growth factor, neurotrophin 3, and glial-derived neurotrophic factor,¹¹ and the survival, development, and function of neural cells. (33) In vitro, vitamin D stimulates macrophages, which increases the clearance of amyloid plaques, a hallmark of AD.^{7,8} Vitamin D also reduces amyloid-induced cytotoxicity and apoptosis in primary cortical neurons. (9) A recent study found that amyloid- β induction of induced nitric oxide synthase, part of the inflammatory process of AD, is dependent on the disruption of the vitamin D-vitamin D receptor pathway. (34) Vitamin D supplementation ameliorates age-related decline in learning and memory in aged rats. (35) In addition, vitamin D deficiency has been linked to cerebrovascular pathology. Meta-analyses establish that 25(OH)D deficiency is associated with an increased risk of incident

stroke, (36) particularly ischemic stroke. (10) A cross-sectional study of 318 elderly adults found that 25(OH)D deficiency was associated with increased white matter hyperintensity volume and a greater number of large vessel infarcts. (37) In summary, low vitamin D concentrations may increase the risk of dementia and AD through both neurodegenerative and vascular mechanisms.

Our study has a number of strengths. The study sample was relatively diverse as it was population-based and included white and African-American men and women. A recent systematic review raised the possibility that the consistent observational associations between vitamin D levels and a wide range of health conditions may simply reflect reverse causation. (38) However, in this study reverse causation is made less likely by the fact that participants were ambulatory and relatively healthy at baseline (their outdoor activity was not likely to be limited by impaired function linked to the onset of dementia). The long follow-up and exclusion of prevalent dementia and incident dementia occurring within a year of baseline also make reverse causation less likely. All-cause dementia and AD in the CHS were diagnosed by a committee of neurologists and psychiatrists using a comprehensive range of data, including neuroimaging, according to international criteria (NINCDS-ADRDA). (23) Our study also has several limitations. While the CHS is multiethnic, it did not incorporate people of Hispanic or other ethnicities. Due to the exclusion of participants with cardiovascular disease and stroke at baseline, there were few cases of incident vascular dementia ($n = 15$). It was therefore not possible to investigate the relationship between vitamin D concentrations and incident vascular dementia due to a lack of statistical power, and further research is necessary to investigate generalizability to older adults with vascular dysfunction. In a cohort with a greater burden of vascular and metabolic dysfunction it would also be interesting to investigate these factors as time-varying covariates. The representativeness of our final sample may have been reduced due to the inability to include participants with insufficient serum volume for 25(OH)D measurement ($n = 945$) as well as those lost to follow-up ($n = 596$). It is possible that the delay between obtaining the blood samples in 1992–1993 and measuring 25(OH)D concentrations in 2008 could have introduced measurement error; however, this is unlikely to have introduced systematic bias. Despite the wide range of information (including repeat neuroimaging) available to the committee diagnosing all-cause dementia and AD, a degree of misclassification is still likely. In particular, many cases of AD may actually reflect a mixture of pathologies, so caution should be exercised when considering potential mechanisms. As with all observational studies, unmeasured confounding is possible, and our findings do not in themselves demonstrate a causal relationship.

We found a strong association between baseline vitamin D concentrations and the risk of incident all-cause dementia and AD over a mean of 5.6 years of follow-up in ambulatory older adults free from vascular conditions at baseline. Further studies are necessary to replicate our findings and extend them to more diverse

populations. It would be useful to conduct prospective studies to investigate the association between vitamin D concentrations and incident vascular dementia and neuroimaging abnormalities. Our findings support the hypothesis that vitamin D may be neuroprotective and that “sufficiency” in the context of dementia risk may be in the region of 50 nmol/L. This information is likely to prove useful in improving the design and reducing the cost of randomized controlled trials investigating whether vitamin D supplements can be used to delay or prevent the onset of dementia and AD in older adults.

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PEDAGOGICAL SCIENCES

INNOVATION AND PRACTICE OF EDUCATIONAL METHODS IN PRIMARY AND SECONDARY SCHOOLS — FROM THE PERSPECTIVE OF STUDENTS' EMOTIONAL MANAGEMENT

Liao XiaoDong

*Abai Kazakh National Pedagogical University
Almaty, Kazakhstan*

Kosherbayeva A.

*Abai Kazakh National Pedagogical University
Almaty, Kazakhstan*

Kalimoldayeva A.

*Abai Kazakh National Pedagogical University
<https://doi.org/10.5281/zenodo.19050750>*

Abstract

Emotional management ability is the core component of primary and secondary school students' mental health development, and also an important breakthrough point for the high-quality development of basic education in the new era. From the perspective of students' emotional management, this paper takes positive psychology as the core theoretical support, and integrates social constructivism, humanistic psychology and other cutting-edge educational theories to analyze the practical dilemmas of emotional management education in primary and secondary schools. Based on the actual teaching practice, this paper explores the innovative paths of educational methods from three dimensions: teaching mode, implementation strategy and collaborative mechanism, and puts forward the systematic implementation strategy of emotional management education. The research aims to promote the normalization and systematic development of emotional management education through the innovation and practice of educational methods, improve the educational effectiveness of primary and secondary schools, and lay a solid foundation for the all-round development and core literacy cultivation of students.

Keywords: Primary and secondary education; Educational methods; Innovative practice; Emotional management; Positive psychology

The main part

With the deepening of the educational reform, the fundamental task of "fostering virtue through education" has put forward higher requirements for the comprehensive development of students. Primary and secondary education is not only committed to the improvement of students' academic performance, but also pays more attention to the cultivation of their mental health and personality quality. The primary and secondary school stage is a critical period for the development of students' emotional cognition and regulation ability. In the face of academic pressure, peer interaction, parent-child relationship and other practical problems, students are prone to produce various emotional fluctuations. Scientific and effective emotional management guidance is an important guarantee for students' healthy growth.

Emotional management education is an important part of mental health education in primary and secondary schools, and its effective implementation is inseparable from the innovation of educational methods. At present, the emotional management education in primary and secondary schools still has some prominent problems in the practice process: the educational form is relatively single, mostly in the form of special lectures and mental health courses, which is difficult to integrate with daily teaching; the educational content focuses on the guidance of negative emotions, lacking the systematic cultivation of positive emotions; the educational implementation is relatively fragmented, and the collaborative education mechanism of school, family and society has not been fully established.

Positive psychology, as a cutting-edge theoretical achievement in the field of psychology, provides a new theoretical perspective for the innovation of emotional management education methods in primary and secondary schools. Breaking through the limitations of traditional psychology focusing on the correction of negative emotions, positive psychology focuses on the cultivation of positive emotions, the construction of psychological resilience and the improvement of subjective well-being, which is highly consistent with the educational goal of promoting students' all-round development in primary and secondary schools. Based on the perspective of students' emotional management, this paper combines cutting-edge educational theories with teaching practice to explore the innovative paths and practical strategies of educational methods, in order to provide practical reference for the high-quality development of primary and secondary education.

Theoretical Basis and Practical Demand for the Innovation of Educational Methods in Primary and Secondary Schools from the Perspective of Emotional Management

Core Theoretical Support

Positive psychology was founded by Seligman and other psychologists in the late 20th century, which is a psychological research paradigm focusing on the positive aspects of human beings. Different from traditional psychology which focuses on the treatment of psychological disorders and the correction of negative emotions, positive psychology takes the cultivation of positive emotions, the development of positive person-

ality traits and the construction of positive social environment as the core research content. It holds that the core of mental health is not only the elimination of negative emotions, but also the full development of positive psychological resources.

In the field of primary and secondary education, the theoretical connotation of positive psychology has important guiding significance for the innovation of emotional management education methods. On the one hand, it requires educators to change the educational concept from "problem correction" to "advantage cultivation", and pay attention to the excavation and cultivation of students' positive emotions such as optimism, gratitude and courage. On the other hand, it emphasizes the importance of psychological resilience and self-efficacy, and guides students to form a positive cognitive style, so as to enhance their internal ability to cope with emotional problems.

Social constructivism holds that human cognitive development is the result of the interaction between individual and social environment, and emotional cognition and regulation ability, as an important part of cognitive development, is also gradually constructed in social interaction. This theory breaks the traditional view of regarding emotional development as a single individual psychological process, and points out that students' emotional learning is closely related to the social environment, especially the interaction with teachers and peers in the educational scene.

The theoretical implication of social constructivism for the innovation of emotional management education methods is mainly reflected in the emphasis on the practicality and interactivity of education. It requires educators to break the one-way teaching mode, design rich and diverse interactive teaching activities, and create a social learning environment for students to perceive, express and exchange emotions. Through cooperative learning, situational simulation and other forms, students can learn emotional management methods in real social interaction, and improve their emotional regulation ability in practice.

Humanistic psychology takes the individual as the center, emphasizes the respect for the individual's emotional needs and the pursuit of self-realization, and holds that the core of education is to create a supportive educational environment to promote the free and full development of the individual. Rogers, the representative of humanistic psychology, put forward the "student-centered" educational concept, which requires educators to establish a good teacher-student relationship based on respect, understanding and acceptance.

For the emotional management education in primary and secondary schools, humanistic psychology provides important theoretical support for the construction of educational environment. On the one hand, it requires teachers to pay attention to the individual differences of students' emotional development, and provide personalized emotional support and guidance according to the different emotional characteristics of students. On the other hand, it emphasizes the creation of a safe and inclusive classroom atmosphere, so that students can bravely express their emotional experience without fear of being denied and evaluated, and lay a

good emotional foundation for the effective implementation of emotional management education.

Practical Demand for the Innovation of Educational Methods in Primary and Secondary Schools from the Perspective of Emotional Management

From the perspective of students' physical and mental development, the emotional development of primary and secondary school students shows obvious stage characteristics. Primary school students are in the critical period of emotional cognition development, with rich emotional experience but weak emotional regulation ability. Their emotional expression is direct and impulsive, and they are easy to produce emotional fluctuations due to small things in study and life. Junior high school students enter adolescence, their self-awareness is significantly enhanced, their emotional experience is more profound and complex, and they are prone to anxiety, irritability, rebellion and other negative emotions. At the same time, their emotional concealment is increased, which brings certain challenges to the detection and guidance of emotional problems.

From the perspective of educational practice, the innovation of emotional management education methods is an urgent need for the development of primary and secondary education. For front-line teachers, there is an urgent need for operable and integrable emotional management education methods, which can integrate emotional management into daily educational work such as subject teaching and class management, instead of being regarded as an "additional task" independent of daily teaching. For parents, with the continuous improvement of their attention to their children's mental health, they need scientific family education guidance to form a joint force of home-school co-education with schools. For the whole society, the implementation of quality education requires the integration of emotional management education with moral education, intellectual education, physical education, aesthetic education and labor education, so as to realize the all-round development of students.

Innovative Paths of Educational Methods in Primary and Secondary Schools from the Perspective of Emotional Management

Constructing an Integrated Teaching Mode of "Positive Cultivation + Diverse Experience"

Classroom is the main position of primary and secondary education, and also the core carrier for the implementation of emotional management education. To realize the innovation of emotional management education methods, the first thing is to break the barrier between emotional management education and subject teaching, and construct an integrated teaching mode of "positive cultivation + diverse experience" with positive psychology as the core, so as to integrate emotional management into the whole process of classroom teaching.

The construction of positive emotional classroom environment is the foundation of integrated teaching mode. Based on the humanistic psychology theory, teachers should transform their educational roles, from the traditional knowledge imparter to the listener and supporter of students' emotions. In the classroom teach-

ing, teachers should respect students' emotional experience, avoid denying and evaluating students' negative emotions, and encourage students to express their true emotions boldly. Setting up a fixed "emotional sharing time" in the classroom can effectively enhance the emotional connection between teachers and students and among students, and make students gain emotional security in the classroom. At the same time, teachers should pay attention to the individual differences of students, and adopt personalized communication and guidance methods for students with different emotional development levels, so as to meet the different emotional needs of students.

Designing diverse experiential teaching activities is the key to the integrated teaching mode. Breaking the traditional didactic teaching mode, based on the social constructivism theory, designing rich and diverse experiential teaching activities according to the age characteristics of primary and secondary school students. For primary school students, we can carry out emotional cognition activities in the form of games, picture books and situational simulation, so that students can perceive the diversity and connotation of emotions in the game. For junior high school students, we can carry out emotional experience activities such as role-playing, psychological drama and group discussion, so that students can experience different emotional states and learn emotional expression and regulation methods. At the same time, teaching students simple and easy emotional regulation skills such as deep breathing, mindfulness meditation and muscle relaxation can help students quickly calm down their emotions when facing negative emotions such as anxiety and irritability.

Promoting the deep integration of emotional management and subject teaching is the core of the integrated teaching mode. Taking the curriculum standards as the basis, integrating the goals of emotional management education into the teaching goals and teaching processes of various subjects, and making each subject a carrier of emotional management education. In Chinese teaching, students can be guided to perceive the emotional experience of characters in the text and improve their emotional cognition ability through the analysis of literary works. In art and music teaching, students can express their emotions through painting, singing and playing, and realize the artistic catharsis of emotions. In moral and rule of law teaching, students can be guided to learn to think from others' perspectives and improve their empathy ability through the analysis of social life cases. In mathematics teaching, aiming at the anxiety of students in solving problems, guiding students to face setbacks correctly and cultivating their anti-frustration ability and psychological resilience.

From "Superficial Guidance" to "In-depth Construction" to Cultivate the Core Competencies of Emotional Management

The innovation of emotional management education methods in primary and secondary schools is not a simple adjustment of educational form, but a fundamental transformation of educational concept and implementation strategy. Guided by positive psychology, we should realize the transformation from "superficial guidance of negative emotions" to "in-depth construction of positive psychological resources", and focus on the cultivation of students' core competencies of emotional management, so that students can form the internal ability of autonomous emotional regulation.

Cognitive restructuring is the basic strategy to help students establish scientific emotional cognition. A large number of research results show that the generation of students' negative emotions is often related to their irrational cognitive style. Teachers should use the cognitive restructuring strategy of positive psychology to guide students to re-examine their negative emotions, let students realize that negative emotions are a normal emotional experience in life, and there is no need to escape or suppress them. For students' irrational cognition such as "absolute thinking" and "overgeneralization", teachers should guide students to correct cognitive deviations through questioning, discussion and other forms, and help students form a positive and scientific cognitive style, so as to reduce the generation of negative emotions from the root.

Setting up moderately challenging tasks is an important strategy to improve students' self-efficacy and psychological resilience. Self-efficacy is an important psychological resource for students' emotional management, and students with high self-efficacy are more able to cope with emotional problems in study and life. Teachers should set up moderately challenging learning tasks according to students' actual learning level, that is, the tasks that students can complete through their own efforts. In the process of students completing the tasks, teachers should pay attention to the process of students' efforts rather than just the results, and give timely encouragement and affirmation to students, so that students can experience the joy of success and enhance their self-efficacy. For students' failure experience, teachers should guide students to analyze the reasons objectively, summarize experience and lessons, instead of denying students' abilities, so as to cultivate students' anti-frustration ability and psychological resilience.

Constructing a diversified evaluation system is the guarantee strategy to promote students' active participation in emotional management. Breaking the traditional score-oriented evaluation mode, constructing a diversified emotional management evaluation system that combines process evaluation and result evaluation, self-evaluation and peer evaluation, teacher evaluation and parent evaluation. The evaluation content should cover multiple dimensions such as emotional recognition ability, emotional expression ability, emotional regulation ability and positive emotion cultivation. The evaluation methods should be diversified, including qualitative evaluation such as emotional diary, learning portfolio and classroom observation, and quantitative evaluation such as emotional scale. The evaluation results should be mainly qualitative feedback, and teachers should put forward personalized improvement suggestions according to each student's evaluation results, guide students to carry out self-reflection, and promote the continuous improvement of students' emotional management ability.

Constructing an Integrated School-Family-Society Collaborative Education System

Students' emotional development is affected by multiple factors such as school, family and society. The effective implementation of emotional management education in primary and secondary schools cannot be separated from the joint efforts of all parties. It is necessary to break the situation of "single fight" of schools, innovate the collaborative education mechanism, and

construct an integrated school-family-society emotional management education system with consistent concepts, coordinated methods and shared resources.

Strengthening home-school communication and cooperation is the core of the collaborative education system. Schools should take various forms such as parent meetings, parent schools and online communication platforms to popularize the scientific concept of emotional management education to parents, and let parents realize the importance of positive emotion cultivation and psychological resilience construction. Schools should provide parents with operable family emotional management education methods, guide parents to establish a democratic and harmonious parent-child relationship, listen to their children's emotional expression, avoid denying and suppressing their children's emotions, and create a good family emotional environment. Establishing a regular home-school emotional feedback mechanism, teachers timely feedback students' emotional state at school to parents, parents take the initiative to communicate their children's emotional performance at home to teachers, and jointly formulate personalized emotional guidance strategies for students' emotional problems, so as to realize the same frequency resonance of home-school education.

Linking social resources and expanding educational carriers is an important supplement to the collaborative education system. Schools should actively connect with social resources such as communities, mental health institutions and universities, and introduce professional mental health education forces into schools. Inviting mental health experts to carry out special lectures, group psychological counseling and other activities in schools can improve the professional level of students, teachers and parents in emotional management. Making full use of community activity venues to carry out parent-child emotional management practice activities can make students improve their emotional management ability in the interaction between family and society. Developing digital emotional management education resources such as micro courses and online psychological counseling platforms can provide convenient learning channels for students and parents, and expand the time and space of emotional management education.

Strengthening teachers' professional training and building a high-quality teaching team is the fundamental guarantee of the collaborative education system. Teachers are the main body of the implementation of emotional management education, and their own emotional management ability and professional quality directly affect the effect of emotional management education. Schools should incorporate positive psychology, emotional management theory, experiential teaching method and other contents into the normalized training of teachers, and improve teachers' professional ability of emotional management education. At the same time, schools should pay attention to the mental health of teachers, establish a teacher psychological support mechanism, help teachers adjust their occupational pressure and negative emotions, make teachers maintain a positive emotional state, and influence students with their own positive emotions.

Practical Guarantee for the Innovation of Educational Methods in Primary and Secondary Schools from the Perspective of Emotional Management

Establishing the Educational Concept of "Integrating Emotion into Teaching and Educating People with Emotion"

Concept is the forerunner of action, and the innovation of emotional management education methods in primary and secondary schools must first strengthen the guidance of educational concept. Schools should take emotional management education as an important part of the school's overall education system, incorporate it into the school's development plan and curriculum construction, and guide all teachers to establish the educational concept of "integrating emotion into teaching and educating people with emotion". Breaking the wrong cognition that "emotional management is the exclusive work of mental health teachers", making every teacher the implementer of emotional management education, and forming a good situation of all staff participation and whole process infiltration. Teachers should take students' emotional development as an important goal of teaching, pay attention to the emotional experience of students in the teaching process, and realize the organic combination of knowledge teaching and emotional education.

Improving the Institutional Guarantee System for the Implementation of Emotional Management Education

The effective implementation of emotional management education method innovation needs a perfect institutional guarantee system. Schools should establish and improve the relevant management systems of emotional management education, incorporate the implementation of emotional management education into the teachers' teaching evaluation system and class management evaluation system, and formulate clear evaluation standards and incentive mechanisms to stimulate teachers' enthusiasm and initiative in carrying out emotional management education. Setting up special funds for mental health education to provide financial support for the development of emotional management education activities, teacher professional training, and the development of educational resources. Establishing a normalized teaching and research mechanism, regularly organizing teachers to carry out teaching and research activities on emotional management education, exchanging teaching experience, exploring teaching methods, and continuously improving the effectiveness of emotional management education.

Implementing Hierarchical and Differentiated Educational Strategies According to the Stage Characteristics

The emotional development of primary and secondary school students has obvious stage characteristics, and the innovation of emotional management education methods must follow the law of students' physical and mental development, and implement hierarchical and differentiated educational strategies. For primary school students, the focus of emotional management education is on emotional recognition and emotional expression, using vivid and interesting forms such as games, picture books, and situational simulation to help students recognize their own emotions and learn to express emotions in an appropriate way. For junior high school students, the focus of emotional management education is on emotional regulation and psychological resilience cultivation, using forms such as thematic discussion, psychological experience and

case analysis to help students master scientific emotional regulation methods and enhance their ability to cope with negative emotions. At the same time, attention should be paid to the individual differences of students, and personalized educational guidance should be provided according to the different emotional characteristics and development levels of students.

Conclusion and Prospect

From the perspective of students' emotional management, the innovation and practice of educational methods in primary and secondary schools is an important measure to implement the fundamental task of "fostering virtue through education" and promote the high-quality development of primary and secondary education. Taking positive psychology as the core theoretical support, and integrating social constructivism, humanistic psychology and other cutting-edge educational theories, this paper explores the innovative paths of educational methods from three dimensions: classroom teaching mode, educational implementation strategy and school-family-society collaborative mechanism, which effectively breaks the practical dilemmas of emotional management education in primary and secondary schools such as single form, superficial implementation and lack of collaboration.

The core of the innovation of educational methods from the perspective of emotional management is to realize three fundamental transformations: first, the transformation of educational concept from "valuing academic performance over psychology" to "valuing both academic performance and psychology", highlighting the important educational value of emotional management; second, the transformation of educational form from "one-way teaching" to "diverse experience", making students the main body of emotional learning, and improving students' emotional management ability in interaction and practice; third, the transformation of educational implementation from "single implementation by schools" to "collaborative implementation by schools, families and society", forming an all-round, multi-level and three-dimensional collaborative education system. The innovative practice of these educational methods is conducive to promoting the normalization and systematic development of emotional management education in primary and secondary schools, improving the educational effectiveness of primary and secondary schools, and laying a solid foundation for the all-round development and core literacy cultivation of students.

With the continuous development of education and the continuous emergence of new technologies, the innovation of emotional management education methods in primary and secondary schools still has a lot of exploration space. In the future, we can combine arti-

cial intelligence, virtual reality and other modern educational technologies to develop personalized emotional management evaluation and guidance systems, and design immersive emotional experience scenarios, so as to further improve the pertinence and effectiveness of emotional management education. At the same time, it is necessary to strengthen the practical research of emotional management education, carry out long-term follow-up research on the effect of emotional management education, sum up replicable and promotable educational experience and methods, and continuously promote the innovation and development of emotional management education in primary and secondary schools. It is necessary to further strengthen international educational exchanges and cooperation, learn from the advanced experience of foreign emotional management education, combine with the actual situation of China's primary and secondary education, and form an emotional management education system with Chinese characteristics.

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POLITICAL SCIENCES

FROM ENERGY CORRIDORS TO DIGITAL CORRIDORS: PROSPECTS FOR KAZAKHSTAN–GCC COOPERATION IN AI GOVERNANCE AND DATA INFRASTRUCTURE

Abu Shawer Omar Ahmad

2nd year PhD student, Department of International Relations, Sorbonne-Kazakhstan Institute, Abai Kazakh National Pedagogical University, Almaty, Kazakhstan

ORCID: <https://orcid.org/0009-0008-1883-8588>

<https://doi.org/10.5281/zenodo.19050754>

Abstract

The redistribution of global influence in the twenty-first century is no longer defined exclusively by control over physical resources or transportation routes. Increasingly, strategic power is embedded in digital infrastructure, data governance frameworks, and artificial intelligence regulation. Kazakhstan and the Gulf Cooperation Council states—particularly Saudi Arabia, the United Arab Emirates, and Qatar—have historically interacted through energy trade and capital flows. Yet their simultaneous digital transformation agendas remain largely unconnected at the institutional level. This article introduces the concept of a digital corridor as an analytical lens for examining the prospects of structured cooperation in data infrastructure and AI governance between Central Asia and the Gulf region. Drawing on international political economy and structural power theory, the study evaluates national digital strategies and assesses whether converging diversification priorities create a realistic foundation for regulatory dialogue and infrastructure interconnection. The analysis argues that although a formal digital corridor does not currently exist, strategic convergence and shared modernization objectives make such cooperation both plausible and potentially consequential for regional positioning within emerging global digital governance structures.

Keywords: Digital corridors, AI governance, Data sovereignty, Kazakhstan, Saudi Arabia, United Arab Emirates, Qatar, International political economy

International political economy is experiencing a structural transition. In previous decades, strategic relevance was largely associated with pipelines, ports, and maritime routes that connected producers and consumers of hydrocarbons. Today, however, digital ecosystems—comprising data centers, cloud infrastructure, and regulatory standards—play an increasingly decisive role in shaping economic resilience and geopolitical influence. Control over data flows functions as a contemporary form of structural power, shaping the environment within which states operate and compete [5, p. 24].

Kazakhstan and the Gulf Cooperation Council states share comparable developmental trajectories. Both regions have historically relied on hydrocarbon revenues while simultaneously seeking economic diversification under conditions of global uncertainty. Kazakhstan's State Program "Digital Kazakhstan," adopted in 2017, emphasizes modernization of public administration, digital industry development, and technological infrastructure expansion [1, p. 3]. In parallel, Saudi Arabia institutionalized data governance through the creation of the Saudi Data and Artificial Intelligence Authority within the broader framework of Vision 2030 [2, p. 12]. The United Arab Emirates advanced regulatory experimentation through its National Strategy for Artificial Intelligence 2031 [3, p. 7], while Qatar embedded AI policy within its long-term national development planning [4, p. 15].

Despite these parallel transformations, Kazakhstan–GCC cooperation remains primarily concentrated in traditional domains such as energy trade, logistics, and sovereign investment. There is no structured framework linking their digital infrastructures or harmonizing their AI governance regimes. This absence should

not be interpreted as stagnation but rather as an undeveloped dimension of otherwise expanding relations.

From a structural power perspective, influence in the digital era derives not merely from technological ownership but from the capacity to shape standards, protocols, and regulatory norms [5, p. 30]. A potential digital corridor would therefore extend beyond technical connectivity. It would require regulatory dialogue, cybersecurity coordination, mutual recognition of data protection principles, and interoperable cloud environments. Without governance compatibility, infrastructure alone cannot produce sustainable digital integration.

Complex interdependence theory further suggests that digital integration generates both opportunity and vulnerability [6, p. 45]. Greater connectivity enhances innovation and market access, yet it simultaneously increases exposure to cyber risks and external regulatory pressures. For Kazakhstan, deeper engagement with Gulf partners could diversify technological partnerships and reduce asymmetric reliance on dominant global platforms. For GCC states, Central Asia offers geographic connectivity between European and Asian markets, potentially reinforcing their role as transregional digital hubs.

However, political coordination and trust-building mechanisms remain essential preconditions. Regulatory divergence, cybersecurity sensitivities, and shifting geopolitical alignments may complicate harmonization efforts. Without institutional anchoring—such as memoranda of understanding in digital governance or regular intergovernmental consultations—digital interaction risks remaining ad hoc rather than strategic.

The transition from energy corridors to digital corridors therefore represents not a replacement of traditional connectivity, but an expansion of its logic into the digital domain. As global influence increasingly depends on servers, standards, and algorithmic architectures, Kazakhstan and the GCC states face a shared strategic question: whether parallel digital ambitions can evolve into coordinated frameworks that enhance autonomy, resilience, and bargaining capacity in the emerging digital order.

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PSYCHOLOGICAL SCIENCES

THE IMPACT OF EDUCATIONAL STRESS ON LEARNING OUTCOMES IN ADOLESCENTS

Mirzəyeva S.

Sumgayit State University, associate professor

Mustafazadə D.

Sumgayit State University, associate professor

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Abstract

This study was conducted to study the role of educational stress in adolescents in terms of learning outcomes. The aim is to identify the stress factors that schoolchildren encounter in their daily educational process, and to study how this stress affects their approach to lessons, attention and motivation. The study involved 9th and 10th grade students, and a 15-question questionnaire developed by the author based on the ESSA (Educational Stress Scale for Adolescents) was used as the method. The questionnaire included questions about the causes of students' stress, their stress level and the impact of this situation on their learning outcomes. Based on the results obtained, it was determined that exam fear, high parental expectations and pressure to achieve results are among the main stress factors in adolescents. At the same time, it was observed that this stress distracts students, reduces motivation and negatively affects overall academic achievement. Teachers' attitudes and classroom competition were sometimes cited as additional stressors. Although the results were consistent with a number of international studies, the differences were explained by cultural and social context. Based on the study results, recommendations were made to increase psychological support in schools, educate parents, change attitudes towards exams, and teach adolescents ways to cope with stress.

Keywords: academic stress, causes of stress, learning outcomes, stress, stress management

GİRİŞ

Problem durumu. Müasir təhsil sistemi yeniyetmələr üçün həm intellektual inkişaf imkanları, həm də ciddi psixoloji yüklənmələr yaradır. Araşdırmalar göstərir ki, tədris proqramlarının yüklü olması, yüksək gözləntilər və imtahan təzyiqləri yeniyetmələrdə stres səviyyəsinin artmasına səbəb olur (Pascoe və digərləri, 2, Hetrick, & Parker, 2020). Bu stres vəziyyəti isə onların dərslə motivasiyasına, yaddaşına və ümumi akademik performansına mənfi təsir edə bilər. Yeniyetmə dövrü emosional və psixososial dəyişikliklərin intensiv yaşandığı bir mərhələ olduğundan, bu yaş qrupunda təhsil stresinin təsirləri daha dərin ola bilər (Compas və digərləri, et al., 2017).

Bəzi tədqiqatlar sübut edir ki, uzunmüddətli təhsil stressi konsentrasiya problemlərinə, dərslə marağın azalmasına və nəticədə akademik göstəricilərin zəifləməsinə gətirib çıxarır (Putwain, 2007). Çində aparılan bir araşdırmada isə qeyd olunur ki, akademik stres akademik yanma ilə müsbət əlaqəlidir və akademik özünə inam bu əlaqəni zəiflədir. Bu, akademik stresin yeniyetmələrin tədris nəticələrinə təsirləri göstərən mühüm bir faktordur (Gao, 2023).

Bu tədqiqatların nəticələri göstərir ki, akademik stres yeniyetmələrin təlim nəticələrinə mənfi təsir göstərir və bu təsirin qarşısını almaq üçün effektiv müdaxilə strategiyalarının inkişaf etdirilməsi vacibdir.

Hazırkı tədqiqat yeniyetmələrdə təhsil stresinin səviyyəsini, bu stresin əsas səbəblərini və onların təlim nəticələrinə təsirini araşdırmaqla, mövcud boşluqları doldurmağı və praktik tövsiyələr formalaşdırmağı qarşıya məqsəd olaraq qoyur.

Tədqiqatın məqsədi. Müasir dövrdə artıq təhsil mühiti rəqabətə əsaslanan və tələbkar bir sistmə çevrilir. Yeniyetmələr bu sistemin mərkəzində yer alan,

həm sosial, həm psixoloji, həm də akademik təzyiqlərə məruz qalan qrup olaraq xüsusilə diqqət çəkir. Yeniyetməlik dövrü emosional dəyişikliklərin və şəxsiyyət formalaşmasının intensiv getdiyi bir mərhələ olduğu üçün, bu yaşda qarşılaşılan stres amilləri təlim prosesinə birbaşa təsir göstərə bilər.

Tədqiqatın əsas məqsədi yeniyetmələrin təhsil həyatında qarşılaşdığı stresin onların təlim nəticələrinə necə və nə dərəcədə təsir etdiyini müəyyən etməkdir. Tədqiqat vasitəsilə eyni zamanda bu stresin yaranma mənbələrini müəyyənləşdirmək və həmin stresin yeniyetmələrin diqqət, motivasiya və yaddaş kimi akademik funksiyalarına necə təsir etdiyini öyrənmək nəzərdə tutulur.

Tədqiqatın aparılması ehtiyacı ondan irəli gəlir ki, məktəblərdə və ümumilikdə təhsil sistemində stresin təsirləri çox zaman diqqətə alınmır, yaxud problemin kökündə hansı faktorların durduğu dərindən araşdırılmır. Məlumdur Baxmayaraq ki, stressə məruz qalan şagirdlərdə akademik nailiyyətlərinin azalması, məktəbə qarşı mənfi münasibətin formalaşması və psixoloji narahatlıqların artması kimi xüsusiyyətlər müşahidə olunur. Bu səbəbdən bu mövzu üzrə araşdırma aparmaq, həm psixoloji, həm pedaqoji baxımdan aktual və ehtiyac duyulan bir mövzudur.

Tədqiqatın əhəmiyyəti/aktuallığı. Müasir dövrdə təhsil sistemində dəyişikliklər, tədris yükünün artması, imtahanların çoxluğu və valideyn-müəllim gözləntiləri şagirdlər, xüsusilə də yeniyetmələr üçün əlavə psixoloji yük yaradır (Pascoe və digərləri, 2020). Yeniyetməlik dövrü insan həyatında emosional dəyişikliklərin və şəxsiyyətin formalaşmasının mühüm mərhələsi olduğundan, bu yaşda yaranan təhsil stresinin həm psixoloji, həm də akademik nəticələri daha dərin və uzunmüddətli ola bilər. Bu səbəbdən bu

dövrədə yeniyetmələrin yaşadığı stresin səviyyəsinin və onun təlim nəticələrinə təsirinin öyrənilməsi olduqca aktualıq kəsb edir.

Bu tədqiqatın əhəmiyyəti ondan ibarətdir ki, təhsil stresinin səbəbləri və nəticələri barədə ətraflı məlumat əldə etməklə müəllimlərə, valideynlərə eyni zamanda, məktəb rəhbərlərinə yeniyetmələrə daha düzgün yanaşma üçün yollar təklif edilə bilər. Əldə olunan nəticələr əsasında məktəb mühitinin psixoloji cəhətdən daha sağlam olması, tədris proqramlarının şagirdin inkişaf səviyyəsinə uyğunlaşdırılması və dəstək mexanizmlərinin qurulması mümkün ola bilər. Bundan əlavə, tədqiqat nəticələri psixoloji müdaxilələr və təlim-tərbiyə metodlarının təkmilləşdirilməsi üçün də faydalı olacaq. Məsələn, yeniyetmələrdə stresin azaldılması məqsədilə keçiriləcək məşğələlər, fərdi və ya qrup dəstəyi proqramları bu tədqiqatın nəticələrinə əsaslanaraq daha hədəfli şəkildə qurula bilər.

Tədqiqatın yeniliyi/orijinallığı. Bu tədqiqatın əsas fərqi ondan ibarətdir ki, burada yeniyetmələrin gündəlik məktəb həyatında qarşılaşdıqları təhsil stresinin onların təlim nəticələrinə necə təsir etdiyi birbaşa onların öz fikirləri əsasında öyrənilməyə çalışılıb. Əvvəllər bu mövzuda ümumi yanaşmalar olub (Pascoe və digərləri, 2020; Deb və digərləri, 2015), , amma konkret olaraq yerli məktəblərdə oxuyan şagirdlərin yaşadıkları stresin hansı səbəblərdən qaynaqlandığı və bunun dərslərinə necə təsir etdiyi tam araşdırılmayıb.

Bu iş eyni zamanda aktualdır, çünki həm beynəlxalq, həm də yerli tədqiqatlarda şagirdlər arasında imtahan qorxusu, valideyn təzyiqi və müəllim münasibətlərinin yaratdığı narahatlıqlar artan tendensiya göstərir. Məsələn, Deb və digərləri (2015) Hindistan məktəblərində bu problemləri sənədləşdirmiş, Pascoe və digərləri (2020) isə daha geniş global kontekstdə stresin təsirini araşdırmışdır. Azərbaycanda isə Rüstəmov və digərləri (2023) məktəblilər arasında imtahan narahatlığını psixoloji dayanıqlıq və məktəbdən məmnunluqla əlaqəli şəkildə öyrənmişdir. hazırda məktəblərdə şagirdlər arasında narahatlıq, imtahan qorxusu, valideyn təzyiqi və müəllim davranışları ilə bağlı problemlər çox müşahidə olunur . Bu səbəbdən belə bir tədqiqat, gələcəkdə məktəblərdə psixoloji dəstək tədbirlərinin hazırlanmasına və müəllim-valideyn münasibətlərinin daha düzgün qurulmasına kömək edə bilər.

Tədqiqat sualları. Bu tədqiqatda əsas məqsəd yeniyetmələrin dərslər zamanı və ümumilikdə təhsil prosesində yaşadıkları stres səviyyəsini, stresin səbəblərini və bu stresin onların təlim nəticələrinə necə təsir etdiyini araşdırmaqdır.

Tədqiqatda aşağıdakı suallara cavab tapmağa çalışılıb:

1. Yeniyetmələr dərslər vaxtı nə qədər stres yaşayırlar?
2. Onların stres keçirməsində hansı səbəblər daha çox rol oynayır?
3. Yeniyetmələrin dərslərində və qiymətlərində təhsil stressi necə rol oynayır?Stres yeniyetmələrin dərslərinə və qiymətlərinə necə təsir edir?

Yeniyetmələrdə təhsil stresinin təlim nəticələrinə təsiri

Tədqiqatda əsas dəyişənlər kimi stres səviyyəsi, stresin səbəbləri və stresin təlim nəticələrinə təsiri seçilmişdir. Dəyişənlərin tədqiqı əvvəlki araşdırmalardatədqiqatlarda geniş şəkildə yer almışdır (Gonzalez və digərləri, 2018; Herman və digərləri, 2018; Şahbazi və digərləri, 2021). Bu tədqiqatda dəyişənlərin qiymətləndirilməsi 15 maddədən ibarət anket vasitəsilə aparılmışdır. Bu anket respondentlərin fərdi təcrübə və hisslərini ölçməyə imkan verir və öncəki tədqiqatlarda da effektivliyi sübut olunmuşdur (Cohen və digərləri., Kamarck & Mermelstein , 1983).

Stres insanın daxili və xarici təzyiqlərə qarşı verdiyi fiziki və psixoloji reaksiyaların məcmusudur. Hans Selye (1956) tərəfindən irəli sürülmüş “Ümumi adaptasiya sindromu” nəzəriyyəsinə əsasən, stres üç mərhələdə həyəcan, müqavimət və tükənmədə inkişaf edir. Xüsusilə yeniyetməlik dövrü fərdin emosional həssaslığı və sosial təzyiqlərə qarşı dayanıqlılığının zəif olduğu bir mərhələdir (Steinberg, 2014). Bu dövrdə yaşanan dəyişikliklər hormonal balanssızlıqlar, şəxsiyyət axtarışı və sosial uyğunlaşma stresin yaranması üçün əlverişli zəmin yaradır (Erikson, 1968). Stresə qarşı fərdi reaksiya, onun psixoloji möhkəmliyindən (resilience) və sosial dəstək sistemlərindən asılıdır (Luthar və digərləri, Cicchetti & Becker, 2000). Bəzi yeniyetmələr stressi motivasiyaedici faktor kimi qəbul etsə də, digərlərində bu, əqli yorğunluğa və motivasiya çatışmazlığına səbəb ola bilər. Yeniyetmələr stressə fərqli səviyyələrdə reaksiya verirlər ki, bu da onların yaş, cinsiyyət, ailə mühiti və fərdi psixoloji xüsusiyyətləri ilə sıx əlaqəlidir. Tədqiqatlar göstərir ki, eyni stres amilinə qarşı bəzi yeniyetmələr aqressiv və impulsiv davranışlarla reaksiya verərkən, digərləri isə özlərinqapanma, motivasiya itkisi və ya somatik əlamətlərlə (məsələn, baş ağrısı, yuxusuzluq) reaksiya verirlər (Compas və digərləri, et al ., 2017). Bu fərqliliklər əsasən stresin qavranması, emosiya tənzimləmə bacarığı və sosial dəstək səviyyəsi ilə əlaqələndirilir (Zimmer-Gembeck & Skinner, 2016). Stresə verdikləri reaksiyalar həmçinin adaptiv və ya maladaptiv strategiyaların istifadəsinə görə dəyişə bilər. Məsələn, bəzi yeniyetmələr stress vəziyyətində problem həll etmə, sosial dəstək axtarma kimi adaptiv strategiyalara üstünlük verərkən, digərləri isə qaçma, inkar etmə və ya özünü günahlandırma kimi maladaptiv strategiyalardan istifadə edə bilirlər (Connor-Smith et al., 2000). Bu yanaşma fərqləri onların psixoloji rifahına da təsir edir; adaptiv strategiyalar ümumiyyətlə daha aşağı depressiya və təşviş anksiyete səviyyələri ilə əlaqələndirilir (Hampel & Petermann, 2006). Yeniyetmələrdə stresin əsas səbəbləri arasında akademik təzyiqlər, müəllim və valideyn gözləntiləri, yaşadılarla münasibətlərdə yaşanan konfliktlər, sosial mediada rəqabət və gələcəklə bağlı qeyri-müəyyənliklər yer alır (Compas və digərləri et al., 2017; Luthar və digərləri et al., 2000). Bu faktorlar təkcə emosional narahatlıqla nəticələnmir, eyni zamanda yeniyetmələrdə psixosomatik əlamətlərin yuxusuzluq, baş ağrısı, qidalanma pozuntuları yaranmasına da səbəb ola bilər (McLeod, 2010).

Yeniyetməlik dövrü insan həyatının ən kritik inkişaf mərhələlərindən biridir. Bu yaşda yaşanan

fiziki, emosional və sosial dəyişikliklərə əlavə olaraq, təhsil sistemi tərəfindən qoyulan yüksək akademik tələblər yeniyetmələrdə təhsil stresinin yaranmasına səbəb olur (Compas və digərləri, 2017). Təhsil stressi dedikdə, təhsil prosesində qarşılaşılan təzyiqlər, imtahan qorxusu, valideyn və müəllim gözləntiləri, dərslərin çoxluğu kimi faktorlar nəticəsində yaranan psixoloji və fizioloji gərginlik başa düşülür (Putwain, 2007). Bu stres növü yeniyetmənin həm zehni, həm də emosional sağlamlığına mənfi təsir göstərə bilər (Ormrod, 2017). Araşdırmalar göstərir ki, davamlı akademik stres şagirdin performansında enişə, diqqətin yayılmasına, yaddaş zəifliyinə və motivasiya azalmasına gətirib çıxarır (Putwain, 2007; Vogel & Schwabe, 2016). Akademik stresin yeniyetmələrdə əsas nəticələrindən biri onların təhsil prosesində performansının azalmasıdır. Stres diqqətin dağılmasına, yaddaşın zəifləməsinə və öyrənmə motivasiyasının düşməsinə səbəb olur (Vogel & Schwabe, 2016). Uzun müddətli təhsil stressi məktəbə qarşı mənfi münasibətin formalaşmasına, davranış pozuntularına və hətta təhsil uğursuzluğuna gətirib çıxara bilər (McLeod, 2010). Yeniyetmələrdə təhsil stressi ilə mübarizə bacarıqları fərqli səviyyələrdə olur. Lazarus və Folkman (1984) stresin idarə olunmasını fərdin stressə necə yanaşdığı ilə əlaqələndirmişdir. Onların transaksional modelinə əsasən, əgər fərd təzyiqi idarəolunan və ya dəstəklə aradan qaldırıla bilən kimi qiymətləndirirsə, onun reaksiyası daha müsbət olur.

Yeniyetmələr stresslə mübarizə aparmaq üçün fərqli yanaşmalardan istifadə edirlər və bu strategiyalar ümumilikdə iki əsas qrupa bölünür: adaptiv (uyğunlaşmanı asanlaşdıran) və maladaptiv (uyğunlaşmanı çətinləşdirən) yollar. Adaptiv strategiyalar arasında problemə yönəlmiş həll yolları, emosiyaların ifadəsi, sosial dəstək axtarma və vəziyyəti yenidən mənalandırma kimi üsullar yer alır. Bu strategiyalar, yeniyetmələrin emosional sabitliyini qorumağa, stressə qarşı daha dayanıqlı olmağa və eyni zamanda təhsil fəaliyyətlərini davam etdirməyə kömək edir (Compas və digərləri et al., 2001). Bununla yanaşı, effektiv mübarizə bacarıqları yetərincə formalaşmamış gənclər, adətən maladaptiv üsullara – məsələn, emosiyaların inkarı, vəziyyətdən qaçmaq, özünü günahlandırmaq və ya aqressiv davranışlar – üstünlük verirlər. Belə yanaşmalar uzunmüddətli dövrdə psixoloji sağlamlığa mənfi təsir göstərərək, depressiya və anksiyete riskini artırır (Seiffge-Krenke, 2004). Eyni zamanda, öz emosiyalarını idarə etməyi və sakitləşmə bacarıqlarını inkişaf etdirən yeniyetmələr stresslə daha sağlam şəkildə mübarizə aparmağa meyilli olurlar (Zimmer-Gembeck & Skinner, 2011). Sosial dəstək də bu prosesdə mühüm əhəmiyyət daşıyır. Ailədən, dostlardan və müəllimlərdən gələn dəstək yeniyetmələrin özlərini daha güvənli və nəzarətli hiss etmələrini təmin edir. Tədqiqatlar göstərir ki, sosial dəstək alan gənclər stressli vəziyyətlərdə daha az narahatlıq yaşayır və daha çox adaptiv strategiyalardan istifadə edirlər. Bu isə onların həm şəxsi, həm də akademik həyatına müsbət təsir edir (Frydenberg & Lewis, 2009). Digər tərəfdən, adekvat sosial dəstək sistemlərinin (məsələn, ailə, müəllim və ya psixoloq

dəstəyi) mövcudluğu yeniyetmənin psixoloji möhkəmliyini artırır (Cohen və digərləri et al., 1983). Sosial dəstək, fərdi adaptasiya strategiyaları və psixoloji möhkəmlik (resilience) bu stresin təsirlərini azaltmaqda mühüm rol oynayır (Luthar və digərləri, Cicchetti & Becker, 2000). Eyni zamanda, valideyn və müəllimlərin təhsil prosesində yaratdığı pozitiv mühit və düzgün dəstək stressi azaltmağa və təhsil nəticələrini yaxşılaşdırmağa kömək edir (Əliyeva, 2020). Azərbaycanda təhsil sistemində yüksək akademik tələblər, repetitorluq kimi əlavə yüklər və ciddi qiymətləndirmə prosedurları yeniyetmələrdə təhsil stresinin əsas səbəbləri kimi göstərilir (Əliyeva, 2020). Belə şəraitdə stres səviyyəsinin yüksəlməsi təhsil nəticələrinə mənfi təsir göstərir ki, bu da yeniyetmələrin ümumi psixoloji vəziyyətinə mənfi təsir göstərir.

Metodologiya

Bu tədqiqat miqdar yönümlü yəni kəmiyyət metodu vasitəsilə aparılmışdır. Tədqiqatın əsas məqsədi yeniyetmələrdə stres səviyyəsinin, onun yaranma səbəblərinin və təhsil nəticələrinə təsirinin öyrənilməsidir. Toplanmış məlumatlar statistik göstərici faiz vasitəsilə təhlil olunmuşdur.

Tədqiqat Mingəçevir şəhərində yerləşən bir tam orta məktəbdə həyata keçirilmişdir. Tədqiqatda bu məktəbin 9 və 10-cu sinif şagirdləri iştirak etmişdir. Ümumilikdə 80 nəfər respondent tədqiqatda iştirak etmişdir. İştirak könüllü olmuş və heç bir məcburiyyət tətbiq olunmamışdır. Respondentlərin yaş həddi əsasən 14-16 yaş aralığında olmuşdur.

Tədqiqatda məlumatların toplanması üçün sorğu-anket metodundan istifadə edilmişdir. Anket tərtib olunarkən beynəlxalq səviyyədə tanınan ESSA (Educational Stress Scale for Adolescents – Yeniyetmələr üçün Təhsil Stressi Ölçeği) anketi əsas götürülmüşdür. Lakin təqdim olunan suallar tədqiqatın məqsəd və vəzifələrinə uyğunlaşdırılaraq tərtib edilmiş və respondentlərin yaş xüsusiyyətlərinə uyğun redaktə olunmuşdur. Bu baxımdan anket ESSA modelinə uyğun hazırlansa da, müəllif tərəfindən müəyyən düzəlişlər edilmişdir. Tədqiqat üçün 15 sualdan ibarət anket hazırlanmışdır. Suallar üç əsas istiqamət üzrə qurulmuşdur:

Stres səviyyəsi ilə bağlı (1–5-ci suallar)

Stresin səbəbləri (6–10-cu suallar)

Stresin təhsil nəticələrinə təsiri (11–15-ci suallar)

Hər suala cavab üçün beş variant təqdim olunmuşdur: Heç vaxt, Nadir hallarda, Bəzən, Tez-tez və Həmişə. Respondentlər onlara uyğun olan cavab variantını seçmişdir.

Anket respondentlərə dərslər vaxtı paylanmış və şifahi izahdan sonra cavablandırılmışdır. Şagirdlər suallara yazılı şəkildə cavab vermiş və anketlər anonim şəkildə toplanmışdır. Toplanmış cavablar Excel cədvəllərinə köçürülərək suallar üzrə cavabların faiz göstəriciləri hesablanmışdır. Tədqiqatın təhlili zamanı hər bir suala verilən cavabların faiz göstəriciləri əsasında ümumi istiqamət müəyyən olunmuş, xüsusən hansı vəziyyətlərdə şagirdlərin daha çox stres yaşadığını və həmin stresin təhsil nəticələrinə necə təsir etdiyini öyrənilmişdir.

Nəticə

Bu bölmədə yeniyetmələr arasında keçirilmiş sorğu nəticələri əsasında təhsil stresinin səviyyəsi, səbəbləri və onun təlim nəticələrinə təsiri ilə bağlı əldə edilən əsas göstəricilər təqdim olunmuşdur. Məlumatlar 15 suallıq anketin cavablarının faiz göstəricilərinə əsasən ümumiləşdirilmiş və aşağıdakı formada qeyd olunmuşdur.

I. Stres səviyyəsi ilə bağlı nəticələr: Dərs zamanı gərginlik və narahatlıq hissi ilə bağlı cavablardan aydın oldu ki, şagirdlərin əksəriyyəti ((%46,2%5) bu hissi heç vaxt yaşamır. Amma şagirdlərin %26,25%-i müəyyən dövrlərdə (bəzən, tez-tez, həmişə) belə gərginlik keçirdiyini qeyd edib. Bu da, bəzi şagirdlər üçün dərs prosesinin stres yarada biləcəyini göstərir.

İmtahanlar yaxınlaşdıqda stresin artması sualına cavab olaraq şagirdlərin %31,25%-i həmişə, %15%-i isə tez-tez stres keçirdiklərini qeyd etmişdir. Alınmış nəticə göstərir ki, imtahanlar bir çox şagird üçün ciddi stres mənbəyidir.

Ev tapşırıqlarının yaratdığı narahatlıq sualına əksəriyyət (%45%-i (heç vaxt cavabı)) bu narahatlığı heç vaxt keçirmədiyini bildirib. Buda onu göstərir ki, ev tapşırıqları ümumilikdə şagirdlər üçün böyük stres mənbəyi deyil.

Yeni mövzular öyrənərkən hiss edilən qorxu və həyəcan haqqında suala verilən cavablar göstərdi ki, %60% iştirakçı bu hissi heç vaxt keçirmir. Bu da şagirdlərin yeni bilikləri öyrənməyə açıq olduqlarını və bu prosesin onlarda stres yaratmadığını göstərir.

Stresin gündəlik həyata təsiri sualına cavab verənlərin %31,25%-i (tez-tez və həmişə cavabları) bu təsiri hiss etdiklərini bildirib ki, bu da bəzi şagirdlərdə təlim zamanı yaranan stresin onların gündəlik yaşamında təsir etdiyini sübut edir.

II. Stresin səbəbləri ilə bağlı nəticələr: Valideyn gözləntiləri ilə bağlı təzyiq hissi sualında şagirdlərin əksəriyyəti ((%41,25%)) bu təzyiqi heç vaxt hiss etmədiklərini bildirib. Lakin %47,5%-lik bir qrup müəyyən dərəcədə valideyn təzyiqini yaşadıklarını qeyd edib.

Müəllim davranışlarının yaratdığı stres ilə bağlı sualda şagirdlərin %51,25%-i heç vaxt belə hiss keçirmədiyini, %32,5%-i isə müəyyən hallarda stres yaşadığını bildirib.

Sınıf yoldaşları ilə rəqabətə görə stressə təzyiq hissi sualına verilən cavablardan aydın olur ki, %56,25% şagird bu hissi heç vaxt keçirmir. Bu, rəqabətin şagirdlər arasında ümumilikdə aşağı olduğunu və stressə səbəb olmadığını göstərir.

Qiymət almaq qorxusundan yaranan stres haqqında olan suala verilən cavablarda %41,25% şagird heç vaxt bunun onlara təsir etmədiyini bildirib. Lakin %50%-dən çox şagird müəyyən səviyyədə bu qorxunu yaşadığını bildirib. Bu, qiymətləndirmənin stres yaradan faktor olduğunu göstərir.

Gələcək imtahanlar haqqında düşüncələrin yaratdığı stres isə yüksək faizlə qeyd olunub %32,5% iştirakçı həmişə, %17,5% isə tez-tez bu narahatlığı yaşadığını bildirib. Bu da onu göstərir ki, gələcək planlar və imtahanlar bir çox şagird üçün əsas stres mənbəyidir.

III. Stresin təlim nəticələrinə təsiri ilə bağlı nəticələr:

Stres zamanı dərslərə diqqət yetirməkdə yaranan çətinliklə bağlı suala cavab verənlərin %60%-dan çoxu bu vəziyyəti zaman-zaman yaşadıklarını qeyd edib. %40% isə bu halı ümumi olaraq yaşamadığını qeyd edib. Buna əsasən demək olar ki, stres eyni zamanda tədris prosesinə də mənfi təsir göstərir.

Stres zamanı öyrənilən məlumatların unudulması ilə bağlı suala verilən cavablardan məlum olur ki, şagirdlərin %55%-dən çoxu bu halları yaşadıklarını, %45 % yaşamadığını bildirib. Bu nəticə stresin yaddaşa təsir etdiyində sübut edir.

Oxumağa marağın azalması ilə bağlı suala verilən cavablar göstərir ki, %47,5% şagird müəyyən dərəcədə oxumağa maraqlarının azaldığını qeyd edib. %32,5% şagird isə stresin onların oxuma həvəsinə təsir etmədiyini qeyd edib. Bu, stresin motivasiyaya mənfi təsir etdiyini göstərir.

Yüksək stres zamanı qiymətlərin aşağı düşməsi sualında şagirdlərin %53,75%-i bu halı yaşadıklarını, %46,25% isə yaşamadıklarını bildirib. Buna əsasən demək olar ki, stres akademik göstəricilərə də mənfi təsir göstərir.

Stresin məktəbə münasibətdə dəyişiklik yaratması ilə bağlı suala verilən cavablarda isə %43,75% şagird bu dəyişikliyi hiss etdiyini qeyd edib. %56,25% isə stresin məktəbə münasibətlərini dəyişmədiyini qeyd edib. Bu, uzunmüddət davam edən stresin məktəbə olan emosional münasibəti dəyişə bildiyini göstərir.

Müzakirə

Azərbaycanda "yeniyetmələrdə təhsil stresinin təlim nəticələrinə təsiri" mövzusunda genişmiqyaslı və empirik əsaslara söykənən tədqiqatlara demək olar ki, rast gəlinmir. Azərbaycanda imtahan stressi və onun təsirləri mövzusunda bəzi tədqiqatlar mövcuddur. Məsələn, Psixologiya Elmi-Tədqiqat İnstitutunun əməkdaşları tərəfindən aparılan bir araşdırmada, 13-18 yaş arası 1819 yeniyetmə arasında imtahan narahatlığı, psixoloji dözümlülük və məktəb məmnuniyyəti arasındakı əlaqələr öyrənilmişdir (Rüstəmov və digərləri, 2023). Əlavə olaraq, Əliyeva (2020) imtahan stresinin səbəbləri arasında valideynlərin və müəllimlərin yüksək gözləntilərini qeyd etmişdir. Təhsil stresinin təlim nəticələrinə təsiri barədə heç bir mənbəyə rast gəlinmir.

Bu tədqiqatın nəticələrinin bir sıra beynəlxalq tədqiqatlarla oxşarlıq və fərqlilikləri mövcuddur. Məsələn, Misra və Castillo (2004) ABŞ-də aparılmış araşdırmada qeyd edirlər ki, tələbələrdə akademik stresin əsas səbəbləri imtahanlar, vaxt çatışmazlığı və mükəmməllik gözləntiləridir. Bu tədqiqatda da imtahan qorxusu və nəticə ilə bağlı narahatlıq əsas stres mənbələri kimi göstərilmişdir ki, bu da nəticələrin qlobal səviyyədə ümumi tendensiyalara uyğun olduğunu göstərir.

Deb və digərləri et al. (2015) Hindistanda apardıqları tədqiqatda göstərmişlər ki, akademik stres məktəblilərin psixi sağlamlığına və tədris nəticələrinə mənfi təsir edir. Həmçinin bu tədqiqatda da stresin diqqət və motivasiya üzərində təsiri qeyd olunmuşdur ki, bu da əldə olunan nəticələrlə uzlaşır. Eyni zamanda, bu tədqiqatda iştirak edənlərin əksəriyyəti ev tapşırıqları və yeni mövzularla bağlı yüksək səviyyəli

stres yaşamadıklarını bildirsələr də, bu faktorların tamamilə təsirsiz olduğunu qeyd etmək olmaz. Aydın olur ki, stres fərdi yanaşmalara bağlı olaraq dəyişir. Bu, Lazarus və Folkman (1984) tərəfindən irəli sürülmüş "fərdi qiymətləndirmə" nəzəriyyəsi ilə də üst-üstə düşür; yəni, fərdlərin stressə reaksiyası eyni hadisəyə fərqli yanaşmalarından asılıdır.

Tədqiqatdan aydın olur ki, stresin təlim nəticələrinə təsiri həm diqqət pozuntuları, həm də yaddaş zəifləməsi formasında özünü göstərir. Bu, Kaplan və Sadock (2015) tərəfindən qeyd olunan psixoloji amillərin koqnitiv funksiyalara təsiri ilə də uyğunluq təşkil edir. Şagirdlərin çox hissəsi qeyd edib ki, yüksək stres yaşadıkları dövrdə motivasiyalarında azalma müşahidə olunur və bu da onların nailiyyətlərinə mənfi təsir göstərir.

Bununla yanaşı, bəzi fərqliliklər də mövcuddur. Məsələn, Qərb ölkələrində, xüsusilə ABŞ və Avropa ölkələrində, müəllimlərin dəstəyi şagirdlərə təsir edən müsbət faktor kimi qiymətləndirilir (Ang & Huan, 2006). Lakin bizim mövcud tədqiqatda bəzi iştirakçılar müəllim davranışlarını stresin səbəblərindən biri kimi qeyd ediblər. Bu fərqliliklər yerli təhsil sistemində müəllim-şagird münasibətlərinin xarakteri və şagirdlərin gözləntiləri ilə bağlı ola bilər.

Digər bir fərq sinif yoldaşları ilə rəqabət məsələsində özünü göstərir. Ryan (2001) və Li et al. (2012) araşdırmalarında akademik rəqabət şagirdlər üçün ciddi stres mənbəyi kimi göstərilmişdir. Halbuki bu tədqiqatda bu amil önəmli stres faktoru kimi qiymətləndirilməyib. Bu isə mədəni xüsusiyyətlərlə, xüsusilə kollektiv münasibətlərin və qarşılıqlı yardımlaşmanın üstünlük təşkil etməsi ilə izah edilə bilər.

Ümumilikdə, bu tədqiqatın nəticələri beynəlxalq tədqiqatların nəticələri ilə ümumi tendensiyalar göstərsə də, mədəni və sosial fərqliliklər stresin formalaşmasında və təsirlərində özünü göstərir. Buna əsasən demək olar ki, akademik stresin təhlilində həm ümumi beynəlxalq, həm də lokal amillər nəzərə alınmalıdır.

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Quliyeva Ş.

Sumgayit State University, Ph.D., associate professor

Abdullayeva A.

Sumgayit State University, master's degree<https://doi.org/10.5281/zenodo.19050758>**Abstract**

Bullying in schools can have profound psychological effects on both the students who are exposed and those who witness it. Students who are exposed to bullying may experience problems such as low self-esteem, anxiety, depression, and isolation. This can negatively affect the victim's school performance and reduce their motivation to study. Students who are exposed to bullying may often feel inadequate and may tend to avoid social interactions. In addition, traumatic experiences resulting from bullying may lead to trust issues in future relationships. This may also negatively affect the emotional health of students and they may have difficulty developing coping mechanisms due to the stress they experience. Students who witness bullying may also be affected by these events. Lack of empathy, difficulty in emotional connection, and feelings of guilt can negatively affect the psychological health of students who witness it. At the same time, students who are exposed to an environment where bullying is common may worry about their safety. Therefore, combating bullying in schools and providing emotional support to students is very important for protecting the psychological health of both victims and witnesses. School staff should strive to develop sensitivity and empathy towards students, implement effective strategies to prevent violence, and create a positive learning environment.

Keywords: schoolchildren, bullying, psychological symptoms, strength, development, personality

Cases of exposure to violence and aggression among schoolchildren are still among the current problems of today. This phenomenon, called bullying, is observed when schoolchildren put pressure on each other morally and physically. Children's hostile attitude towards their peers, their use of force over them causes the victim of bullying to have difficulty defending themselves, lack of self-confidence, a tendency to be lonely, and be easily deceived by strangers. Studies show that people who practice and show bullying are those who have physical superiority and a strong body shape. The victims of bullying are mostly weak, emotional, constantly depressed, and children who are weak in communication. They play the role of victims. Bullies are usually people who like to draw attention to themselves and tend to be dominant. Therefore, they choose a weak point for themselves. Therefore, they observe in advance which child in the class to bully". Aybeniz Zamanova, who said that there are types of violence among schoolchildren such as cyberbullying, social bullying, and verbal bullying, said that cyberbullying is more widespread in modern times. The psychologist said that cyberbullying mainly occurs in upper grades and among teenagers: "Schoolchildren share their photos and make threats. Currently, we most often encounter group correspondence on social networks regarding bullying. School psychologists and social workers must definitely inform students about bullying. If a child bullies another, the first person to take action is called the one who comes to their aid (the victim), the one who intervenes. In this case, the person who is bullied during the incident does not feel alone. However, when this person who comes to help does not know what to do or how to help during bullying, he begins to withdraw. At this time, the bully begins to press another classmate or other student even more. The bully threatens the person in front of him by saying, "Carry

my bag," "You are weak," and throwing him out of his group."

Expressing his opinion on the subject, education expert Elmin Nuri said that according to studies, all children encounter bullying sooner or later: "The term bullying was first used in 1985 when a study was conducted in Great Britain schools. The roles of victim, victimized person, or witness have a devastating effect on the child's personality. According to a report by the US Department of Education, one in four children aged 12 to 18 has been a victim of bullying during the last school year. According to research conducted for UNICEF in Ukraine, 89 percent of schoolchildren encounter bullying. According to Western sources, 50 percent of students under the age of 14 are bullied at school. This percentage drops as they get older.

Research in this area in Russian schools began in the late 2000s. It was revealed that bullying is a widespread phenomenon. In 2010, researchers found that 22 percent of boys and 21 percent of girls under the age of 11 had been bullied by their peers. A survey of 1,200 students in Moscow found that 78 percent of them had witnessed bullying at school. Among teenagers, the figures were 13 and 12 percent, respectively.

In Norway, 11 percent of boys and 21 percent of girls 2.5 percent admitted to engaging in aggressive behavior towards their peers, such as bullying. Currently, research on bullying is being conducted in countries such as the USA, France, Britain, Finland, and South Korea. The expert said that, compared to foreign countries, when assessing the quantity and quality of education in Azerbaijani secondary schools, the number and reasons for bullying incidents occurring during the year are not indicated: "Although the details of the reasons are more or less known to many, it is not so easy to estimate the quantitative indicators. I think that official statistics should be announced in this direction, and the Ministry of Science and Education should provide the

society with statistical data. Because in order to know whether any problem related to bullying or other incidents has changed for the better or worse in the next academic year, we can only make a comparison between quantitative indicators and come to the right conclusion. I do not see a serious problem with disclosing bullying incidents occurring in local secondary schools and registered on the basis of official complaints. The incidence of bullying in our schools is very low compared to similar incidents in many countries. There are other reasons for this, including certain mentalities and the quality of education. Especially in rural schools, the closer relationship between the population and the compact living space factor are the main reasons for preventing bullying among students.

The sharp reactions of society to the bullying incidents experienced in recent years, their coverage and publicization through the media, have led to a more sensitive approach to such incidents in the educational community. However, we have not witnessed any reporting information on the results of those incidents or the investigations conducted for a long time. The work done by the Baku City Education Department in this direction, the institution's immediate response to bullying incidents and the subsequent disclosure of the results of the incident to the public should be considered commendable. However, it is very useful to have a general annual report at the end of each academic year solely on bullying incidents. Unfortunately, there is no report on the quantity, cause, psychological details, criteria for occurrence of bullying incidents, as well as their consequences and preventive measures taken. The existence of this report could also play the role of a much-needed database for the media.

Bullying, like the phenomenon of deviant behavior, is an acute socially significant problem during school years. In almost every school, in every class, there are schoolchildren with characteristics that distinguish them from their peers. Distinctive schoolchildren's characteristics often lead to ridicule and violence in the classroom. Episodic aggression, school violence is called bullying in modern science. In public consciousness and in the media, the problems of bullying are presented in a rather modified and truncated form. Society believes that bullying occurs rarely and is limited only to individual cases involving socially disadvantaged citizens. However, this is not so, bullying exists in all categories of the population, regardless of socio-economic, racial, cultural, demographic aspects. Violations that arise as a result of a schoolchild's exposure to bullying lead to certain changes, and they affect all levels of human activity (Audmayer, 2016).

In the conditions of modern educational activity, the development of psycho-correctional and preventive programs aimed at preventing or preventing violence in the classroom has become necessary. Such programs should be implemented at the initial stages of team formation and be based on a systematic approach, that is, they should involve work not only directly with schoolchildren, but also with the pedagogical and administrative staff of the school, as well as with parents. Pro-

grams based on bullying factors will provide high-quality and long-term assistance in achieving results (Malkina-Pykh, 2016).

The problem of bullying has always existed at all stages of human life (both in childhood in educational institutions and in adulthood at work). Adolescence is the most difficult, contradictory and controversial stage of personality development. At this stage, physical and psychological changes, puberty, and a person's search for his own "I" take place. For a teenager, education takes a back seat, and peers become a reference group. Situations such as the struggle for leadership and conflict are observed. Despite the fact that the participation of a schoolchild in conflicts is quite normal, the problem of bullying has been occurring for a long time. In the struggle for leadership, everyone wants to assert themselves against the background of other peers, and persecution begins. It is very difficult for the "victim" to change his status, as he is constantly subjected to attacks from the "criminal" and his friends. It is important to prevent and stop any attempts at violence among schoolchildren. The relevance of the problem of bullying prevention lies in the fact that it is necessary to create universal ways of combating this problem in schools. b, many teachers do not pay attention to or do not want to note violence among schoolchildren, therefore, the necessary support for the "victim", as well as the "criminal", is not provided in a timely manner. Bullying is beginning to take new forms. It is more difficult for modern schoolchildren who are "victims" of bullying to avoid situations of violence that negatively affect their psychological state and may have consequences in adulthood (Olweus, 1993). The problem of bullying is a wide area of study in psychology, sociology, clinical psychology, criminology, medicine, pedagogy, philosophy and other fields of scientific knowledge. The first works dedicated to the problem of bullying began to be published in 1905. The first studies were conducted by Scandinavian scientists (D. Olweus, E. Roland, P. Heinemann), and then by British scientists (D. Lane). Abroad, much attention is paid to this problem, where there are very well-established effective programs to prevent violence. In domestic psychology, bullying was not generally recognized as a specific phenomenon until recently. In schools and science, the problem of bullying has long been considered a category of problems that are considered to be hushed up. However, recently, interest in the problem of bullying in psychology has increased and is gradually becoming more stable. At the modern stage of development of society, negative trends in interpersonal relationships in the educational environment are widespread. Such distribution is often expressed in various forms of pressure and, as a rule, has the character of violence against a person, and this can be directly defined as the problem of bullying. Determining measures to prevent bullying in the educational environment is a multifaceted phenomenon that requires a complex approach. In order to understand bullying in the educational environment and consider the main approaches, it is first of all necessary to refer to the definition of bullying in general. Thus, this term is understood as an attempt on the personal safety of a person in the form of intentional physical or mental

harm to the victim against his will by means of energy (physical) or information (mental) impact on the human body. Indeed, a social problem such as bullying should be classified in terms of causing specific harm to a person by negatively affecting their psychophysiological state. Such harm should, first of all, be of a preventive nature, aimed at eliminating factors that disrupt the stability of behavioral relationships. In turn, G. Azimli gives the following description of the concept under consideration: "Bullying is broadly interpreted as:

- applying physical force to someone;
- forcibly influencing someone, something, using force to achieve something;
- oppression, lawlessness (Azimli, 2008, p.328).

Thus, this phenomenon is characterized by various aspects, which are primarily the criminogenic consequences of the violation of human rights and freedoms, personal integrity. School bullying is a variety of systematic actions of the perpetrator of the crime aimed at humiliating the victim through physical, psychological, economic or sexual aggression. Bullying can arise from a certain antisocial attitude as a result of the deviant behavior of the perpetrator of the crime. Such actions are expressed by various illegal means of influence aimed at causing any harm determined by public danger (Alizadeh, 2004).

School bullying is a significant problem in many countries (Borntrager et al., 2009; Eslea et al., 2003). The term "school bullying" is defined by most modern researchers as violence. As A. Alizadeh noted, this term was first introduced by the English journalist Andrew Adams in the early 90s of the 20th century (Alizadeh, 2004, p.236). At the same time, the concept of "school

violence" appeared. N. Huseynova notes that in psychology, the problem of school bullying, denoted by the scientific term "bullying", has a longer and more extensive research history than the problem of school bullying (Huseynova, 2018, p.66).

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EXPERIMENTAL STUDY OF STUDENT STRESS LEVELS DURING THE EDUCATIONAL PROCESS**Hacıyeva A.***Sumgayit State University, associate professor***Rzayeva S.***Sumgayit State University, master's student*<https://doi.org/10.5281/zenodo.19050760>**Abstract**

Stress is a widespread phenomenon among university students, significantly affecting their psychological and physical health as well as academic performance. High expectations related to academic activities, heavy coursework, examination pressure, expectations from parents and instructors, financial difficulties, and social competition are among the key factors contributing to student stress. Investigating these factors is crucial for improving students' psychological wellbeing, enhancing academic performance, and supporting their adaptation to the university environment. The aim of this study was to examine the dynamics of academic stress across different courses and gender differences among students at Sumgayit State University, as well as to identify the main factors influencing stress. The study employed a quantitative methodology, involving 200 students (100 female, 100 male), and data were collected using the Neuroticism scale of the Eysenck Personality Questionnaire (EPQ).

The results revealed that stress levels were highest among first- and fourth-year students. First-year students experienced high stress due to adaptation challenges related to academic and social demands, whereas fourth-year students showed elevated stress levels due to concerns about graduation, examinations, and future career prospects. Stress levels in the second and third years were moderate and relatively stable, which may be attributed to increased academic experience and skills. From a gender perspective, female students exhibited higher stress levels compared to males. This difference can be explained by females' tendency to respond more emotionally, their openness in expressing stress, and the use of adaptive coping strategies.

The main factors affecting student stress were identified as concerns about future careers, financial difficulties, academic workload, and the imbalance between personal life and academic responsibilities. These findings are valuable for universities to enhance psychological support, implement stress management programs, and develop individualized support strategies considering gender differences. Overall, this study clearly outlines the dynamics of academic stress, gender differences, and the key influencing factors, providing practical recommendations to improve students' psychological wellbeing and support academic success.

Xülasə

Stress, universitet tələbələri arasında geniş yayılan və onların psixoloji, fiziki sağlamlığına, həmçinin akademik nəticələrinə ciddi təsir göstərən bir fenomendir. Akademik fəaliyyətlə bağlı qarşıya qoyulan yüksək gözləntilər, dərslər yükü, imtahan təzyiqləri, valideynlərin və müəllimlərin gözləntiləri, maddi çətinliklər və sosial rəqabət kimi faktorlar tələbələrdə stressin yaranmasına səbəb olur. Bu amillərin tədqiqi tələbələrin psixoloji rifahının yaxşılaşdırılması, akademik performansın artırılması və universitet mühitinə adaptasiyanın dəstəklənməsi baxımından xüsusi əhəmiyyət kəsb edir. Bu araşdırmanın məqsədi Sumqayıt Dövlət Universitetində müxtəlif ixtisaslarda təhsil alan tələbələr arasında akademik stressin kurslar üzrə dinamikasını və gender fərqlərini araşdırmaq, həmçinin stressə təsir edən əsas faktorları müəyyən etməkdir. Tədqiqat kəmiyyət metodologiyası əsasında 200 tələbə (100 qadın, 100 kişi) arasında aparılmış, məlumatlar Ayzenkin Şəxsiyyət Sorğusunun Nevrotiklik şkalası vasitəsilə toplanmışdır.

Nəticələr göstərmişdir ki, stress səviyyəsi ən yüksək I və IV kurs tələbələri arasında müşahidə olunur. I kurs tələbələri universitet həyatına adaptasiya mərhələsində akademik və sosial çətinliklərdən irəli gələn yüksək stress yaşayır, IV kurs tələbələri isə diplom işi, imtahanlar və gələcək karyera ilə bağlı narahatlıqlar səbəbindən yüksək stress səviyyəsi nümayiş etdirir. II və III kurslarda stress səviyyəsi orta və nisbətən sabit olaraq qalır, bu isə tələbələrin akademik təcrübə və bacarıqlarının artması ilə əlaqələndirilə bilər. Gender aspektinə baxdıqda, qadın tələbələrdə yüksək stress səviyyəsi kişilərlə müqayisədə daha çox olmuşdur. Bu fərq qadınların daha emosional reaksiya verməsi, stressi ifadə etməkdə daha açıq olmaları və adaptiv başa çıxma strategiyalarından istifadə etməsi ilə izah edilə bilər.

Tədqiqatda tələbələrin stressinə təsir edən əsas faktorlar gələcək karyera ilə bağlı narahatlıqlar, maddi çətinliklər, akademik yük və şəxsi həyatla dərslər öhdəlikləri arasında balanssızlıq kimi müəyyən edilmişdir. Bu nəticələr universitetlər üçün tələbələrin psixoloji dəstəyini gücləndirmək, stressin idarə olunması proqramlarını tətbiq etmək və gender fərqlərini nəzərə alaraq fərdiləşdirilmiş dəstək strategiyaları hazırlamaq baxımından vacibdir. Ümumilikdə, bu araşdırma akademik stressin dinamikasını, gender fərqlərini və əsas təsir faktorlarını aydın şəkildə ortaya qoyaraq, universitet tələbələrinin psixoloji rifahını artırmaq və akademik uğuru dəstəkləmək üçün praktiki tövsiyələr təqdim edir.

Keywords: Concept of stress, psychological health, stress level, academic performance.**Açar sözlər:** Stress anlayışı, psixoloji sağlamlıq, stress səviyyəsi, akademik performans.

GİRİŞ. Tələbələrin akademik fəaliyyətlərinə dair gözləntiləri ilə bağlı düşüncələri stressin yaranmasına səbəb olur (Khan et., 2013). Bir çox hallarda tələbələr valideynlərinin, müəllimlərin və digər müxtəlif amillərin yaratdığı gözləntilərə görə ciddi akademik təzyiqlə üzləşirlər (Zhang et., 2024). Eyni zamanda tələbələr akademik yük, gələcək qayğısı, karyerası ilə bağlı, həmçinin peşə seçimində qeyrimüəyyənliklər, maddi problemlər kimi müxtəlif səbəblərdən stresslə mübarizə aparmaq məcburiyyətində qalırlar (Olson et., 2025). Stress uzunmüddət davam edərsə, tələbədə müxtəlif sağlamlıq problemlərinin (yuxu pozuntusu, iştahsızlıq, depressiya və s.) yaranmasına səbəb ola bilər. Stress təkcə sağlamlıq problemlərinin yaranmasına gətirib çıxarmır, stressli hadisələrə məruz qalmaq siqaret, spirtli içki, narkotik maddələrin istifadəsi asılılıq riskini artırır (Siquaria et., 2000).

Tədqiqatın yeniliyi. Stress haqqında çoxlu araşdırmalar mövcuddur (Brougham et., 2009; Khan et., 2013; Al-Qahtani & Alsubaie, 2020). Araşdırmaların bir çoxu tələbələrin stress səviyyəsini ümumi şəkildə tədqiq edib (Alzahem et., 2013; Rafique et., 2019), müxtəlif kurslara görə stressin dinamikasını araşdırsa da, tədqiqat nəticələri üst-üstə düşmür, bu səbəbdən bu tədqiqat işinin yenidən aparılmasına ehtiyac duyulmuşdur. Tədqiqatın yenili ondan ibarətdir ki, I-IV universitet tələbələrinin akademik stressin dinamikası empirik üsullarla tədqiq olunaraq öyrəniləcək və stressin dinamikasına təsir edən amillər araşdırılacaqdır.

Tədqiqatın aktuallığı/əhəmiyyəti. Stressə təsir edən amillərin öyrənilməsi, eləcə də universitetin müxtəlif kurslarında tələbələrdə stressin dinamikasının öyrənilməsi aktuallıq və əhəmiyyət daşıyır. Bu tədqiqatda əldə edəcəyimiz nəticələrlə stressin dinamikasını nəzərə alaraq müxtəlif kurslarda təhsil alan tələbələr üçün stressin idarə olunması və qarşısının alınması məqsədi ilə praktik tövsiyələr, dəstək proqramları hazırlana bilər.

Tədqiqatın məqsədi. Universitet tələbələrinin stress səviyyəsinin müxtəlif kurslarda dinamikasını və müxtəlif faktorların, eləcə də gender fərqlərinin stressin dinamikasına necə təsir etdiyini öyrənməkdir.

Tədqiqat sualları:

1. Müxtəlif kurslarda (I-IV) təhsil alan tələbələrin stress səviyyəsi necə dəyişir?
2. Stress səviyyəsi genderə görə fərqlilik göstərirmi?
3. Universitet tələbələrinin stressinin artmasına hansı faktorlar səbəb olur?

Nəzəri çərçivə. Stress, tələbələrin təhsil tələblərini yerinə yetirmək və təhsil məqsədlərinə nail olmaq üçün üzləşdikləri təzyiqlərə cavab olaraq münasibətini əhatə edir (Jagiello et., 2024). Ətraf mühitin qarşılıqlı təsiri, tələbələrin stress, narahatlıq yaşama ehtimalını artırır.

Al-Qahtani və Alsubaie universitet tələbələri arasında tədqiqat aparıb, stressə təsir edən

faktorları araşdırıblar, bu faktorlara fərdi və ətraf mühit faktorları aid edilir. Fərdi faktorlara tələbənin şəxsiyyətinin xüsusiyyətlərini misal göstərmək olar. Ətraf mühit faktorları isə müxtəlifdir. Akademik

stressə təsir edən əsas faktorlara valideynlərin gözləntiləri, təhsil yükü, müəllimlərin tələbləri, ev tapşırıqları, gələcək qayğısı və s. aiddir (Al-Qahtani & Alsubaie, 2020).

Rettew və digərlərinin (2021) apardığı bir araşdırma göstərir ki, nevroitik səviyyəsi yüksək olan tələblərdə stress səviyyəsi digər tələbələrə nisbətən daha yüksək olur. Başqa bir araşdırmada introvert olan tələbələr də stressə daha meyilli olduqları tədqiq edilib (Collings et., 2014). Araşdırmaların birində universitetin psixoloji sağlamlıq xidmətindən və universitetin tələbələrin şəxsi inkişafı və boş zamanını dəyərləndirmək üçün olan xidmətlərindən istifadə edən tələbələr, digər tələbələrə nisbətən daha az stress yaşayırlar. Həmçinin, akademik dəstək xidmətlərindən istifadə edən tələbələr stresslə daha yaxşı mübarizə aparırlar, nəticədə akademik uğur qazanırlar (Amanvermez et., 2020).

Universitetdə təhsil alan tələbələrdə stressin dinamikasının öyrənilməsi üzrə müxtəlif araşdırmalar aparılmışdır. Simon Zacharias Lahme və digərləri tərəfindən aparılan tədqiqatda birinci kurs fizika tələbələrinin semestr boyunca stress səviyyələri izlənilmişdir. Nəticə olaraq göstərilmişdir ki, dərslərinin əvvəlində stress səviyyəsi artır, imtahan dövründə yüksək qalır, tətil zamanı azalır. Stressə təsir edən əsas amillər arasında həftəlik tapşırıqlar, laboratoriya dərsləri və imtahan hazırlıqları qeyd edilmişdir (Lahme et., 2024). Digər bir tədqiqatda stomatologiya tələbələrinin müxtəlif kurslarda stress səviyyələri müqayisə edilmişdir. Nəticədə birinci kurs tələbələri digər kurslarla müqayisədə daha aşağı stress səviyyəsinə malik olduğu qeyd olunmuşdur. Ən yüksək stress səviyyələri üçüncü kurs tələbələrində müşahidə edilmişdir (Alzahem et., 2013). Başqa bir tədqiqatda Tibb ixtisası üzrə təhsil alan tələbələr üzrə aparılmışdır. Nəticədə birinci kurs ən stressli dövr kimi müəyyən edilmişdir. Stress səviyyələri ikinci və üçüncü kursda azalmış, sonuncu kursda yenə stress səviyyəsi yüksəlmişdir (Rafique et., 2019).

Stressə qarşı mübarizəni ümumilikdə 2 kateqoriyaya ayırırlar:

1. Vəziyyətlə üzləşməyə yönəlmiş fəaliyyətlər;
2. Stressli vəziyyətdən uzaqlaşmağa yönəlmiş fəaliyyətlər (Tobin et., 1989).

Müəlliflər stressli vəziyyətlə üzləşməyə yönəlmiş 4 konkret fəaliyyət növü fərqləndirmişlər:

1. Problem həlli- stressi yaranan vəziyyəti dəyişdirməyə yönəlmiş idrak və davranış strategiyaları;
2. İdrak yenidənqurması- stressli vəziyyətin mənasını dəyişdirməyə yönəlmiş idrak strategiyaları;
3. Sosial dəstək- emosional dəstək axtarışı ilə bağlı strategiyalar;
4. Emosional ifadə- stress zamanı yaranan emosiyaların sərbəst buraxılmasına yönəlmiş strategiyalar.

Stressli vəziyyətdən uzaqlaşmağa yönəlmiş fəaliyyətlər aşağıdakılardır:

1. Problemdən qaçma- hadisəyə dair düşüncə və davranışlardan imtina və inkar etməyə yönəlmiş strategiyalar;
2. Arzuolunan düşüncələr- reallığın stressli olmadığına dair arzulardan ibarət idrak strategiyaları;

3. Sosial uzaqlaşma- dostlardan, ailədən və yaxınlardan uzaq durmağa yönəlmiş strategiyalar;

4. Özünü tənqid- stressli vəziyyətin baş verməsi və onunla qeyri-adekvat mübarizəyə görə özünü günahlandırmağa əsaslanan strategiyalar.

Üzləşməyə yönəlmiş mübarizə strategiyaları daha çox adaptiv (uyğunlaşmağa kömək edən), uzaqlaşmağa yönəlmiş strategiyalar isə maladaptiv (uyğunsuz, zərərli) mübarizə formaları kimi qəbul edilir (Jauregui et., 2017).

Metodologiya

Tədqiqat iştirakçıları Sumqayıt Dövlət Universitetinin müxtəlif ixtisaslar üzrə təhsil alan I, II, III, IV kurs bakalavr tələbələrindən ibarətdir. Ümumilikdə tədqiqatda 200 tələbə iştirak etmişdir. İştirakçıların 100 nəfəri qadın, 100 nəfəri isə kişi cinsinə mənsubdur. Kurslara görə iştirakçı sayı- I kurs-50 nəfər, II kurs- 50 nəfər, III kurs-50 nəfər, IV kurs-50 nəfər olmuşdur.

Məlumatların toplanması: Tədqiqat kəmiyyət yanaşması əsasında həyata keçirilmişdir. Məlumatların toplanması Ayzenkin Şəxsiyyət Sorğusu (Eysenck

Personality Questionnaire, EPQ) – Nevrotiklik şkalası vasitəsilə aparılmışdır. Data toplamaq könüllülük prinsipinə əsaslanmışdır. Anketi doldurmaq təqribi orta hesabla 15 dəqiqə çəkmişdir və data toplamaq prosesi əyani olaraq kağız üzərində anonim formasında həyata keçirilmişdir.

Məlumatların təhlili: Anketdəki məlumatlar Microsoft Excel proqramına daxil edilmişdir. Məlumatların təmizlənməsi mərhələsində natamam cavablar ayırd edilərək tədqiqat işindən çıxarılmışdır. Əldə olunmuş nəticələr cədvəl və qrafik təsvir formasında verilmişdir.

Tədqiqatın etik tərəfi: Tədqiqatın bütün mərhələlərində etik prinsiplərə riayət edilmişdir. Tədqiqata başlamazdan əvvəl Sumqayıt Dövlət Universitetinin Tədris-Metodiki Mərkəzinin direktorundan etik icazə, həmçinin tələbələrlə tədqiqat keçirmək üçün icazə alınmışdır. Tədqiqat keçirilən qruplarda tədqiqatın məqsədi və üsulu tədqiqatçı tərəfindən izah olunmuşdur. Həmin tələbələrdən şifahi icazə alınaraq data toplanılmışdır.

NƏTİCƏ

Cədvəl 1.

Tələbələrin kurslara görə stress səviyyəsinin bölgüsü

	Aşağı	Orta	Yüksək
I Kurs (n=50)	12% (n=6)	38% (n=19)	50% (n=25)
II Kurs (n=50)	22% (n=11)	54% (n=27)	24% (n=12)
III Kurs (n=50)	28% (n=14)	50% (n=25)	22% (n=11)
IV Kurs (n=50)	14% (n=7)	40% (n=20)	46% (n=23)

Cədvəl 1-dən göründüyü kimi, I kurs tələbələrinin yarısı (50%) yüksək səviyyədə stress yaşamışdır. Bu göstərici, yeni tələbələrin universitet həyatına adaptasiya prosesi zamanı qarşılaşdıqları akademik və sosial çətinliklərdən irəli gələ bilər. Eyni zamanda, I kurs tələbələrinin 38%-i orta səviyyədə, 12%-i isə aşağı səviyyədə stress keçirdiyini qeyd etmişdir. II kurs tələbələri arasında yüksək stress səviyyəsi 24% təşkil etmişdir ki, bu da I kursla müqayisədə nəzərəcarpacaq dərəcədə azalmışdır. Orta stress səviyyəsi isə 54%-i təşkil etmiş, aşağı stress səviyyəsi isə 22% olmuşdur. Bu göstəricilər II kurs tələbələrinin universitet mühitinə nisbətən uyğunlaşdığını və I kursdakı yüksək stressin azaldığını göstərir. III kurs tələbələrində stress səviyyələri II kurs nəticələrinə yaxın olmuşdur. Belə ki, aşağı stress səviyyəsi 28%, orta stress səviyyəsi 50%,

yüksək stress isə 22% olmuşdur. Bu məlumatlar göstərir ki, təcrübə və akademik bacarıqların artması ilə tələbələrdə stressin idarə olunması yaxşılaşır. IV kurs tələbələri arasında isə yüksək stress nisbəti 46% təşkil etmişdir. Orta səviyyədə stress 40%, aşağı səviyyədə stress isə 14% olmuşdur. Bu göstəricilər göstərir ki, ali təhsilin son kursunda tələbələr, imtahan və diplom işləri ilə əlaqədar, akademik yükün artması səbəbindən yüksək stress yaşayırlar.

Ümumilikdə, nəticələr göstərir ki, universitet tələbələri arasında stress səviyyəsi ən yüksək I və IV kurslarda müşahidə olunur, II və III kurslarda isə stress orta səviyyədə saxlanır. Bu meyl tələbələrin universitetə adaptasiya prosesi və son kurslarda qarşılaşdıqları akademik yükün artması ilə izah oluna bilər.

Cədvəl 2.

Tələbələrin cinsə görə stress səviyyəsinin bölgüsü

	Aşağı	Orta	Yüksək
Kişi (n=100)	31% (n=31)	40% (n=40)	29% (n=29)
Qadın (n=100)	7% (n=7)	51% (n=51)	42% (n=42)

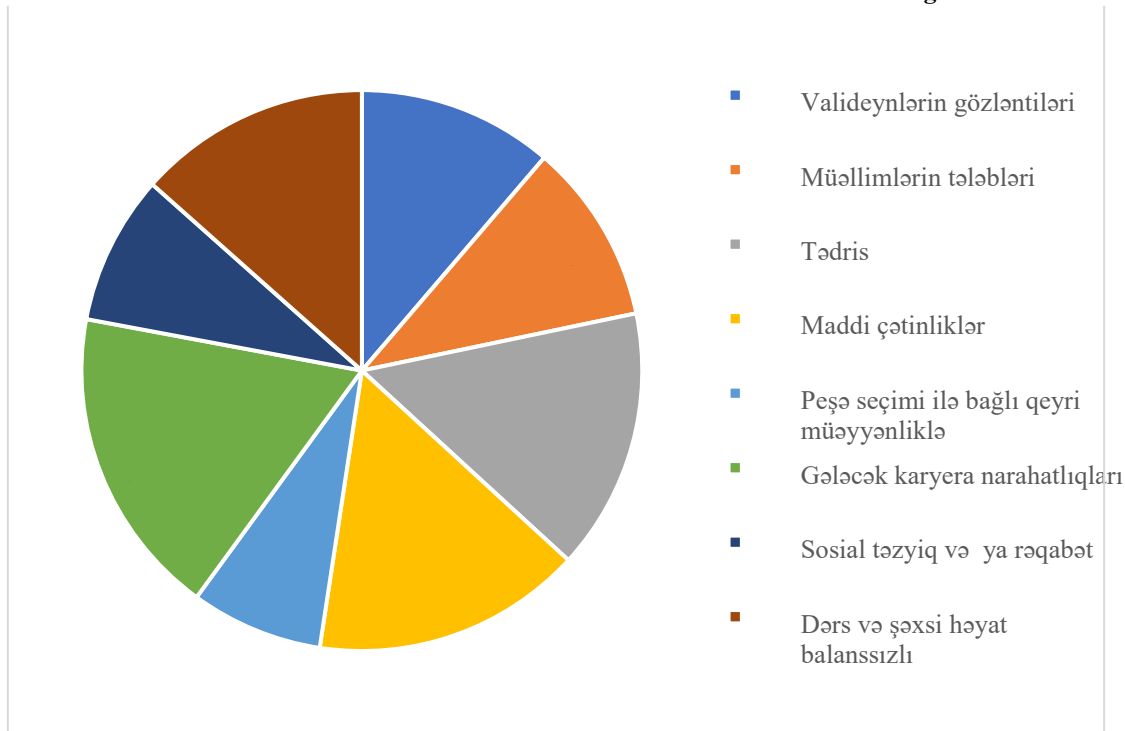
Cədvəl 2-dən göründüyü kimi, kişilər arasında aşağı və orta səviyyəli stress nisbəti qadınlara müqayisədə daha yüksəkdir. Kişi tələbələrin 31%-i aşağı səviyyədə, 40%-i orta səviyyədə, 29%-i isə yüksək səviyyədə stress yaşamışdır. Bu göstəricilər göstərir ki, kişi tələbələri arasında stressin paylanması daha balanslıdır və yüksək səviyyədə stress nisbəti nisbətən azdır. Qadın tələbələr arasında isə vəziyyət fərqlidir. Yalnız 7%-i aşağı səviyyədə stress keçirdiyini

bildirərkən, 51%-i orta və 42%-i yüksək səviyyədə stress yaşamışdır. Bu, qadın tələbələrdə yüksək stressin kişilərlə müqayisədə daha çox olduğunu göstərir.

Nəticələr göstərir ki, gender fərqləri akademik stressin səviyyəsinə təsir edə bilər. Xüsusilə qadın tələbələr, akademik öhdəliklər, imtahanlar və gələcək karyera ilə bağlı narahatlıqlar səbəbindən daha yüksək stress yaşayırlar. Kişilər isə stres faktorlarına nisbətən

daha az reaksiya verir və ya stressi daha effektiv idarə edə bilirlər.

Qrafik 1. Stressə təsir edən əsas faktorların faiz bölgüsü



Qrafik 1-də tələbələrin stress səviyyəsinə təsir edən əsas faktorlar təhlil edilmişdir. Tədqiqatda iştirak edən tələbələrin böyük bir qismi akademik stressin yaranmasına əsas səbəb gələcək karyera narahatlıqları (66,6%), maddi çətinliklər (58,1%), tədris yükü (56,1%), dərs və şəxsi həyat balanssızlığı (50%) faktorlarını qeyd etmişdilər. Akademik stressə təsir edən digər faktorlar isə, valideynlərin gözləntiləri (41,9%), müəllimlərin tələbləri (38,8%), sosial təzyiq və ya rəqabət (32,1%); peşə seçimi ilə bağlı qeyri-müəyyənliklər (28,4%) qeyd olunmuşdur. Tədqiqatın nəticələri göstərir ki, akademik stressə ən çox təsir göstərən faktor gələcək karyera narahatlıqlarıdır. Bununla yanaşı akademik stressə yalnız təhsillə bağlı amillər deyil, bir sıra sosial, iqtisadi, fərdi amillərdə təsir edir.

Tədqiqatın nəticələri göstərir ki, universitet tələbələri arasında akademik stress səviyyəsi kurslar və cinsiyyət görə fərqlilik göstərir.

MÜZAKİRƏ

Bu tədqiqatın məqsədi universitet tələbələrinin müxtəlif kurslar üzrə stressin dinamikasını, gender fərqlərinin mövcudluğunu araşdırmaq, akademik stressə təsir edən əsas faktorları aşkarlamaq idi. Tədqiqatın nəticələrindən də göründüyü kimi, I və IV kurs tələbələrində yüksək stress səviyyəsi müşahidə olunmuşdur. Eləcə də, kişilərə nisbətən qadınlarda stress səviyyəsi nisbətən yüksək təzahür etmişdir.

Brougham və digərləri tərəfindən aparılan bir tədqiqatda kişilərə nisbətən qadınlarda stress səviyyəsinin nisbətən yüksək təzahür olunduğu təsdiq olunur. Araşdırmanın nəticəsi apardığım tədqiqatın nəticəsi ilə üst-üstə düşür. Bu nəticə, qadınların daha çox emosional olması və sosial dəstək alması ilə əlaqələndirilə bilər, həmçinin tədqiqatda qadınlar daha çox emosional başa çıxma strategiyalarından istifadə edirlər, kişilər isə problemdən yayınma və ya özbaşına

həll yollarına üstünlük verirlər. Qadınların daha yüksək stress səviyyəsi göstərməsi onların daha çox emosional yüklənməyə məruz qalması ilə yanaşı, bu yükü ifadə etməkdə daha açıq olmaları ilə də əlaqələndirilə bilər. Kişi tələbələrin daha az stress bildirməsi onların problemdən yayınma və ya kişilərin daha çox daxili aləminə yönəlmələri ilə bağlı ola bilər (Brougham et., 2009).

Abdullah və digərləri tərəfindən aparılan tədqiqatda tələbələrin akademik stressinin akademik performansına, eləcə də, tələbələrin psixoloji sağlamlığına mənfi təsir göstərdiyi müəyyən edilmişdir. Tədqiqatda akademik stress səviyyəsi əsasən IV kursda artdığı qeyd olunur, buna səbəb diplom işi, məzuniyyət və işlə bağlı narahatlıqlar əsas səbəblər kimi verilmişdir. Bu tədqiqatda da həmçinin qadın tələbələrdə kişi tələbələrə nisbətən stress səviyyəsinin daha yüksək olduğu qeyd edilmişdir. Bu tədqiqatın nəticələri apardığım tədqiqatın nəticələri ilə bəzi məqamlarda oxşarlıq təşkil edir. Araşdırmada tələbələrin III, IV kurslara keçdikdə stress səviyyəsinin artdığı və psixoloji sağlamlığının zəiflədiyi qeyd olunub. Həmçinin, hazırkı tədqiqatda da I, IV kurs tələbələri arasında daha yüksək stress səviyyəsi qeydə alınıb. Nəticələrin belə olması diplom işi, gələcək karyera ilə bağlı narahatlıqlarla əlaqələndirilə bilər. Hər iki tədqiqatda tələbələrin stressinə təsir edən başlıca faktor karyera narahatlığı, tədris yükü önə (Abdullah et., 2024).

Təvsiyələr. Tədqiqatın nəticələrinə əsasən tələbələrin akademik performansını və psixoloji rifahını yaxşılaşdırmaq üçün bir sıra tövsiyələr verilə bilər. Akademik stressin tələbələrin emosional sağlamlığına, həmçinin akademik performansına təsirini nəzərə alaraq, ali təhsil müəssisələri səmərəli stressin idarə edilməsi proqramlarının yaradılmasına və həyata keçirilməsinə üstünlük verə bilər. Bu

proqramlara stress ilə mübarizə aparmaq üsullarını və bacarıqlarını öyrətmək üçün hazırlanmış bir neçə seminardan, materiallardan və psixoloji məsləhət xidmətlərindən ibarət ola bilər. Akademik stressin gender fərqlərinə təsirini nəzərə alaraq gender dəstək proqramları da hazırlanması faydalı ola bilər. Universitetlərdə psixoloji məsləhət xidmətləri təşkil oluna bilər, bu psixoloji məsləhət xidmətləri sayəsində tələbənin universitetdə təhsil aldığı müddət boyunca akademik stressinə, psixoloji sağlamlığına təsir edən əsas faktorlar müəyyən edilə bilər, eləcə də fərdiləşdirilmiş strategiyalar yaradıla bilər.

MƏHDUDİYYƏT

Tədqiqat yalnız bir universitetin tələbələri üzrə aparıldığı üçün, həmçinin bu universitetin bölgə universiteti olduğunu üçün bu, məhdudiyyət kimi qəbul edilmişdir.

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TECHNICAL SCIENCES

COMPARATIVE ANALYSIS OF THE APPLICATION OF FAST FOURIER TRANSFORM AND NUMBER-THEORETICAL TRANSFORM IN FULL HOMOMORPHOUS ENCRYPTION SCHEMES

Retivykh A.

lecturer at the Cybersecurity Competence Center, Irkutsk National Research Technical University, Irkutsk, Russia

<https://orcid.org/0000-0001-8362-8247>

Retivykh V.

lecturer at the Cybersecurity Competence Center, Irkutsk National Research Technical University, Irkutsk, Russia

<https://orcid.org/0009-0007-7423-5362>

Marinov A.

PhD in Economic Sciences, associate Professor at the Cybersecurity Competence Center, Irkutsk National Research Technical University, Irkutsk, Russia

<https://orcid.org/0000-0003-2238-2751>

СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПРИМЕНЕНИЯ БЫСТРОГО ПРЕОБРАЗОВАНИЯ ФУРЬЕ И ТЕОРЕТИКО-ЧИСЛОВОГО ПРЕОБРАЗОВАНИЯ В СХЕМАХ ПОЛНОГО ГОМОМОРФНОГО ШИФРОВАНИЯ

Ретивых А.В.

Преподаватель центра компетенций по кибербезопасности, ФГБОУ ВО «Иркутский национальный исследовательский технический университет», г. Иркутск, Россия.

<https://orcid.org/0000-0001-8362-8247>

Ретивых В.В.

Преподаватель центра компетенций по кибербезопасности, ФГБОУ ВО «Иркутский национальный исследовательский технический университет», г. Иркутск, Россия.

<https://orcid.org/0009-0007-7423-5362>

Маринов А.А.

кандидат экономических наук, доцент центра компетенций по кибербезопасности, ФГБОУ ВО «Иркутский национальный исследовательский технический университет», г. Иркутск, Россия.

<https://orcid.org/0000-0003-2238-2751>

<https://doi.org/10.5281/zenodo.19050762>

Abstract

This paper provides an in-depth analysis of two fundamental algorithms – the Fast Fourier Transform (FFT) and the Number Theoretic Transform (NTT) – in the context of their application in Fully Homomorphic Encryption (FHE) systems. It is shown that, despite sharing a common algorithmic basis (the divide-and-conquer strategy) and identical asymptotic complexity of $O(n \log(n))$, the choice between them is dictated by the error model of a specific cryptosystem. A detailed mathematical derivation of NTT for the ring $Z_q[x]/(x^n + 1)$, which underlies the BGV, BFV, and CKKS schemes, is presented. A comparative analysis of accuracy, performance, and hardware implementability is performed. It is established that for schemes with exact integer arithmetic (BGV, BFV), NTT is the only possible choice, while in the approximate computation scheme (CKKS), FFT is used at the data encoding stage, and NTT is used for cryptographic operations.

Аннотация

В работе проводится глубокий анализ двух фундаментальных алгоритмов – Быстрого преобразования Фурье (FFT) и теоретико-числового преобразования (NTT) – в контексте их применения в системах полного гомоморфного шифрования (FHE). Показано, что, несмотря на общую алгоритмическую основу и идентичную асимптотическую сложность $O(n \log(n))$, выбор между ними диктуется моделью ошибок конкретной криптосистемы. Приводится детальный математический вывод NTT для кольца $Z_q[x]/(x^n + 1)$, лежащего в основе схем BGV, BFV и CKKS. Выполнен сравнительный анализ точности, производительности и аппаратной реализуемости. Установлено, что для схем с точной целочисленной арифметикой (BGV, BFV) NTT является единственно возможным выбором, в то время как в схеме приближенных вычислений (CKKS) FFT применяется на этапе кодирования данных, а NTT – для криптографических операций.

Keywords: Number Theoretic Transform (NTT), Fast Fourier Transform (FFT), Fully Homomorphic Encryption (FHE), Lattice-based cryptography, BGV scheme, BFV scheme, CKKS scheme.

Ключевые слова: Теоретико-числовое преобразование (NTT), Быстрое преобразование Фурье (FFT), Полное гомоморфное шифрование (FHE), Криптография на решетках, Схема BGV, Схема BFV, Схема CKKS.

ВВЕДЕНИЕ

Современная криптография переживает переход к постквантовым алгоритмам, среди которых лидирующее положение занимают протоколы, основанные на сложности решения задач в решетках. Одной из наиболее мощных концепций в этом направлении является полное гомоморфное шифрование (Fully Homomorphic Encryption, FHE), позволяющее выполнять произвольные вычисления над зашифрованными данными без их расшифровки [1]. Математической основой большинства эффективных схем FHE (BGV [2], BFV [3], CKKS [4]) являются кольца многочленов вида $R_q = Z_q[x]/(x^n + 1)$, где n – степень двойки (1024, 2048, 4096), а q – большой модуль. Ключевая операция – умножение многочленов в этом кольце. Наивное умножение имеет сложность $O(n^2)$, что является неприемлемым для практического использования FHE.

Задача ускорения умножения многочленов решается с помощью алгоритмов быстрого преобразования Фурье (FFT) [5] и его аналога в конечных полях – теоретико-числового преобразования (NTT) [6]. Оба алгоритма, используя теорему о свертке, позволяют достичь асимптотической сложности $O(n \log(n))$. Однако принципиальные различия в арифметике, комплексные числа с плавающей точкой против целочисленной модульной арифметики, определяют их применимость в FHE.

Целью данной работы является проведение сравнительного анализа NTT и FFT с акцентом на их математические основы и применение в FHE-схемах. Для достижения цели ставятся следующие задачи: 1) дать детальное математическое описание NTT для кольца $Z_q[x]/(x^n + 1)$; 2) провести сравнительный анализ алгоритмов по ключевым параметрам (точность, производительность, гибкость); 3) определить области оптимального использования каждого алгоритма в схемах BGV, BFV и CKKS.

1. Математические основы теоретико-числового преобразования (NTT) в контексте FHE

Теоретико-числовое преобразование является дискретным аналогом преобразования Фурье, перенесенным в конечное поле Z_q .

1.1. Определение и условия существования NTT

Пусть задан вектор $a = (a_0, a_1, \dots, a_{(n-1)})$ с элементами из Z_q , где q – простое число. Дискретное преобразование Фурье над полем Z_q (NTT) вектора a есть вектор $A = (A_0, A_1, \dots, A_{(n-1)})$, компоненты которого вычисляются по формуле:

$$A_k = \sum_{j=0}^{n-1} a_j \cdot \omega^{jk} \pmod{q}, k = 0, 1, \dots, n-1, (1)$$

где ω – примитивный корень n -й степени из единицы в поле Z_q . Для существования преобразования необходимо, чтобы n делило порядок мультипликативной группы поля, т.е. $n \mid (q-1)$. Обратное преобразование (INTT) имеет вид:

$$a_j = n^{-1} \cdot \sum_{k=0}^{n-1} A_k \cdot \omega^{-jk} \pmod{q}, j = 0, 1, \dots, n-1, (2)$$

где n^{-1} – мультипликативно обратный элемент к n по модулю q .

1.2. Негациклическое NTT для кольца $R_q = Z_q[x]/(x^n + 1)$

Для кольца $x^n + 1$, используемого в FHE, применяется модифицированное (негациклическое) NTT. В этом случае необходим примитивный корень ψ степени $2n$ из единицы, для которого $\psi^n \equiv -1 \pmod{q}$. Прямое преобразование вычисляется как:

$$A_k = \sum_{j=0}^{n-1} a_j \cdot \psi^{(2k+1)j} \pmod{q}, k = 0, 1, \dots, n-1. (3)$$

Это преобразование является изоморфизмом между кольцом R_q и векторами длины n , при котором умножению многочленов в кольце соответствует покомпонентное умножение их образов. Эффективное вычисление (3) осуществляется с помощью алгоритма Кули-Тьюки за время $O(n \log(n))$.

2. Сравнительный анализ FFT и NTT для FHE

Выбор между FFT и NTT определяется не только производительностью, но и фундаментальными требованиями к точности вычислений.

2.1. Сравнение по ключевым параметрам

Сравнительный анализ по основным критериям представлен в табл. 1.

Таблица 1.

Сравнение FFT и NTT		
Критерий	FFT	NTT
Область определения	Поле комплексных чисел $\mathbb{C}$.	Конечное поле (поле Галуа) $\text{GF}(q)$ или кольцо вычетов $\mathbb{Z}_q$, где q – простое число.
Базовый элемент (корень из единицы)	Комплексный корень N -й степени из единицы: $\omega_N = e^{(-2\pi i/N)}$. Является трансцендентным элементом.	Целочисленный корень n -й степени из единицы по модулю q : $\omega \in \mathbb{Z}_q$, такой что $\omega^n \equiv 1 \pmod{q}$ и $\omega^k \neq 1$ для $0 < k < n$.
Условие существования преобразования длины n	Отсутствуют алгебраические ограничения, n может быть любым целым числом (для эффективности обычно степень 2).	Строгое алгебраическое условие: $n \mid (q-1)$. Для негациклической свертки (кольцо $x^n + 1$): $2n \mid (q-1)$. Модуль q должен быть выбран специальным образом.
Точность вычислений	Приближенная. Используется арифметика с плавающей точкой (FP32, FP64). Присутствуют ошибки округления, накапливающиеся с глубиной преобразования ($O(\epsilon \log(n))$).	Абсолютная (точная). Используется целочисленная модульная арифметика. Ошибки округления отсутствуют. Результат детерминирован и обратим.
Тип арифметических операций	Операции над числами с плавающей точкой. Сложение, умножение комплексных чисел. Требуют наличия FPU (Floating Point Unit).	Операции над целыми числами по модулю q . Сложение, вычитание, умножение с приведением по модулю. Требуют наличия ALU и умножителей.
Асимптотическая сложность	$O(N \log(N))$ для длины N (основание 2).	$O(N \log(N))$ для длины N (основание 2).
Реализация алгоритма «бабочка»	Вычисляется по формуле: $X = A + \omega \cdot B$; $Y = A - \omega \cdot B$, где ω – комплексный поворотный коэффициент.	Вычисляется по формуле аналогичной FFT, но все операции выполняются по модулю q . $A_k = A_{\text{even}} + \omega^k \cdot A_{\text{odd}} \pmod{q}$.
Стоимость базовой операции («бабочки»)	Высокая. Требует 2 комплексных умножения и 2 комплексных сложения (что эквивалентно множеству операций с плавающей точкой).	Средняя. Требует 2 целочисленных умножения, 2 сложения и 2 операции приведения по модулю (редукции).
Управление динамическим диапазоном	Автоматическое. Числа с плавающей точкой масштабируют результат. Требуется контроль переполнения экспоненты.	Критически важное. Промежуточные результаты могут расти. Требуется либо использование модулей специального вида
Гибкость выбора параметров	Высокая. Длина преобразования N может быть любой, диктуется лишь задачей и кратна степени двойки для максимальной эффективности.	Низкая. Длина преобразования n жестко связана с модулем q . Выбор параметров безопасности FHE (n, q) подчинен условию существования NTT.
Реализация на CPU (x86/ARM)	Высоко оптимизирована. Использует SIMD-инструкции (SSE, AVX, AVX-512, NEON) для векторизации операций с плавающей точкой. Производительность очень высока.	Зависит от оптимизации модульной арифметики. Используются инструкции для целочисленной арифметики (ADCX, ADOX, MULX). При хорошей оптимизации производительность сопоставима с FFT.
Реализация на GPU (CUDA/OpenCL)	Отлично распараллеливается. Существуют готовые библиотеки (cuFFT). Широко используется в научных расчетах и машинном обучении.	Хорошо распараллеливается, но требует оптимизации модульной редукции. Используется в специализированных библиотеках для FHE.
Реализация на ПЛИС (FPGA)	Сложная и ресурсоемкая. Требует реализации блоков операций с плавающей точкой (DSP-блоки в режиме FP), что потребляет много логических ресурсов и энергии.	Высокоэффективная. Целочисленные модульные операции отлично ложатся на аппаратную архитектуру ПЛИС, позволяя достичь высокой тактовой частоты и пропускной способности при низком энергопотреблении.

Реализация на специализированных микросхемах (ASIC)	Экономически нецелесообразна для массового применения из-за сложности FP-блоков, за исключением специализированных процессоров (DSP).	Крайне эффективна. Позволяет создавать специализированные ускорители для FHE с высокой производительностью и энергоэффективностью. Активная область исследований.
Чувствительность к атакам по побочным каналам (Side-Channel Attacks)	Низкая. Время выполнения и энергопотребление могут зависеть от данных из-за особенностей FPU, но это редко используется.	Высокая. Время выполнения модульного умножения и ветвления в алгоритме могут зависеть от секретных ключей.

2.2. Применение в схемах полного гомоморфного шифрования

Различия в природе арифметики приводят к четкому разделению областей применения алгоритмов:

1. Схемы BGV и BFV. Эти схемы работают с целочисленными коэффициентами и требуют точного управления шумом. Ошибки округления FFT неприемлемы. Умножение многочленов реализуется исключительно через NTT. Стандартный пайплайн включает в себя: прямое NTT (3), покомпонентное умножение и обратное INTT. Это де-факто стандарт для библиотек Microsoft SEAL [7] и HElib [8].

2. Схема CKKS. Эта схема предназначена для вычислений над числами с плавающей точкой. Она использует гибридный подход [4]:

- на этапе кодирования вектора комплексных чисел в многочлен применяется IFFT;
- сами гомоморфные операции (умножение шифртекстов) выполняются в кольце R_q и требуют точной арифметики, поэтому здесь используется NTT;
- на этапе декодирования результата применяется FFT.

Заключение

В работе проведен сравнительный анализ применения алгоритмов FFT и NTT в современных схемах полного гомоморфного шифрования. Показано, что, несмотря на общую алгоритмическую основу, их применение не является взаимозаменяемым, а диктуется математической моделью криптосистемы. Главные выводы по данной работе:

1. Для схем BGV и BFV, основанных на точной модульной арифметике, применение FFT невозможно из-за неконтролируемых ошибок округления. NTT является критически важным компонентом, обеспечивающим практическую производительность умножения многочленов.

2. В схеме CKKS реализован гибридный подход: FFT применяется для кодирования и декодирования данных в комплексной области, в то время

как криптографические операции по-прежнему выполняются с использованием NTT для обеспечения корректности вычислений в кольце вычетов.

3. Выбор алгоритма также влияет на аппаратную реализацию: NTT значительно более эффективен при реализации на ПЛИС (FPGA) благодаря простоте целочисленных модульных операций.

Таким образом, понимание математических основ и ограничений NTT и FFT является необходимым условием для разработки эффективных и корректных реализаций систем полного гомоморфного шифрования.

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THE IMPACT OF ARAB INVESTMENTS ON GEORGIA'S ENERGY SECTOR: ENERGY AND SOCIO-ECONOMIC ASPECTS

Pantskhava E.

*PhD, Associate Professor of Georgian Technical University,
Faculty of Power Engineering, Tbilisi, Georgia*

Jishkariani M.

*PhD, Full Professor of Georgian Technical University,
Faculty of Power Engineering, Tbilisi, Georgia
<https://doi.org/10.5281/zenodo.19050764>*

Abstract

The article discusses the impact of Eagle Hills' planned large-scale development project in Georgia on the country's energy sector and socio-economic development. The study analyzes how large infrastructure and urban projects contribute to the growth of electricity demand, the modernization of the energy system, and the stimulation of the development of renewable energy sources. Special attention is paid to the possibility of introducing energy-efficient technologies and their role in establishing sustainable energy systems. The paper also assesses the socio-economic effects of the investment, including employment growth, urban development, tourism expansion, and strengthening the country's investment attractiveness. The study shows that properly planned and managed investment projects can become an important factor in Georgia's economic growth and economic security. The article emphasizes the importance of public-private sector cooperation to ensure sustainable development.

Keywords: Investment, Energy systems, Infrastructure, Renewable energies, Economic security.

Introduction

The world's energy transformation and the needs of developing economies are gaining particular relevance in modern Georgia. Georgia's energy sector, despite progress in the field of renewable energy, still faces energy independence and infrastructure challenges [1]. Foreign direct investment, including large-scale projects of Arab capital, represents a significant stimulus not only for the modernization of the energy sector, but also for economic development, increased employment, and improved urban infrastructure (fig.1). It is important that investment in Georgia's energy sector can become a transformative factor. Its effects include increasing electricity demand, introducing energy-efficient technologies, integrating renewable energy sources, and enhancing the stability of energy systems [2]. Accordingly, this project has a direct impact not only on economic but also on energy sustainability [3].

Research objective

To assess the impact of Arab investment on the Georgian energy sector, to determine the social and economic consequences and present recommendations for energy policy and future development strategies [4].

Main Text

Impact on the energy sector includes:

- Increase in electricity demand: Large-scale urban infrastructure projects are increasing electricity demand, this creates a need to expand power generation, modernize the grid, and strengthen the resilience of energy infrastructure [5].
- Renewable energy integration: The implementation of the project promotes the more active use of renewable energy sources - hydro, solar and wind energy. The investment creates an incentive for the introduction of modern energy-efficient systems, which plays an important role in the process of strengthening Georgia's energy independence [6].

- Energy efficiency and technological innovations: Emaar and Eagle Hills projects will ensure the implementation of energy-efficient buildings, "green" infrastructure and smart energy management systems. This increases energy efficiency, reduces fixed energy costs, and contributes to the establishment of sustainable energy systems [7].

Eagle Hills is a real estate and Arab private investment and development company founded in 2014. Eagle Hills and Emaar share a common founder and chairman – Mohammed Alabar. Eagle Hills has projects in multiple countries [8]. The company's portfolio includes multi-billion dollar projects in the Middle East, Europe, Asia and Africa. According to information published on the official Eagle Hills Properties website, the company has projects in more than 18 countries [9]. The Eagle Hills project will be called Tbilisi Waterfront in Tbilisi [10]. It is to be implemented in the villages of Aghtaklia and Ponichala, adjacent to the Rustavi-Tbilisi highway. The territory also includes the land of the Krtsanisi Forest Park. Eagle Hills plans to develop residential complexes, commercial spaces, hotels, and recreational zones here [11].

Socio-economic impact

- Employment and economic growth: Infrastructure projects create new jobs in both the construction and service sectors. This increases the population's income, economic activity, and leads to the strengthening of local businesses [12].
- Urban and regional development: The development process of Tbilisi and Batumi increases tourist attractiveness, strengthens urban infrastructure, and promotes sustainable development of regions [13].
- Improving the investment environment: The large-scale project strengthens Georgia's position in the eyes of international investors, strengthens the country's investment image and creates conditions for attracting other foreign investments [14].

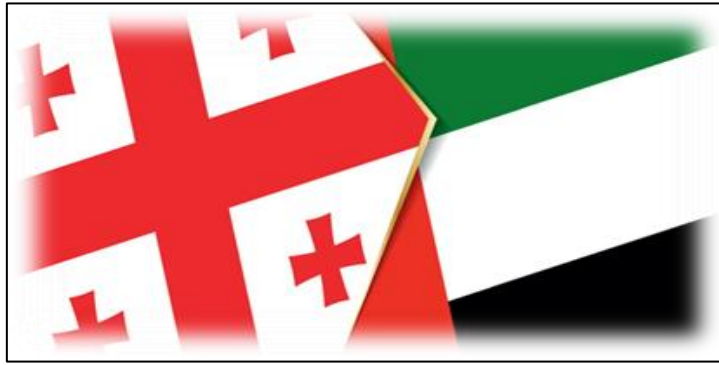


Fig. 1. Relations between Georgia and the United Arab Emirates.

Risks and challenges

- Load on the power system: Ongoing infrastructure projects are increasing electricity demand, with transient or stable power supply problems [15].
- Challenges of renewable energy integration: Integration of hydro, solar, and wind energy sources requires sophisticated management systems and high-quality investments. Technical problems may result in inadequate energy supply or financial loss [16].
- Ecological challenges: Implemented infrastructure projects may impact the environment (rivers, land, urban ecosystems), as a result, it is necessary to introduce eco-innovations and strictly adhere to environmental standards [17].
- Risks of economic dependence: Large-scale foreign investment increases the economic potential of the country, although there are risks of economic dependence [18].
- Risks of economic dependence: Large-scale foreign investment increases the economic potential of the country, although there are risks of economic dependence. Project delays or investor withdrawal could reduce energy and infrastructure benefits [19].
- Planning and coordination challenges: The effectiveness of the project largely depends on public-private sector cooperation, an integrated approach to energy planning, and a legislative framework [20].

Recommendations

- Strong energy sector planning: implement an updated national energy plan; phased expansion of power generation capacity and grid modernization;
- Renewable energy integration: use infrastructure projects to form hybrid energy systems; establish integrated energy management systems to ensure grid stability;
- Energy-efficient technologies: introduction of energy-efficient buildings, "green" infrastructure and smart grid technologies [21]; stimulation of innovations for the private sector;
- Environmental standards: control of environmental assessments and introduction of eco-innovations; creation of monitoring systems;
- Economic sustainability: independent financial assessment of project effectiveness; coordination with investors and robustness of contracts;
- Planning and Policy: The state and the private sector should maintain strategic cooperation; energy policy should be revised every 3-5 years;

This unprecedented project is expected to significantly accelerate economic growth, making it the largest investment in Georgia's history [22].

Conclusion

The results of the research show that large-scale foreign investment in Georgia is a significant stimulus for the development of the energy sector. The project increases electricity demand, stimulates the integration of renewable energies, promotes the introduction of energy-efficient technologies, and strengthens the stability of the energy system. From a socio-economic perspective, the project increases employment, economic activity, urban and regional development, as well as improving the investment environment. Despite the risks, strategic planning, energy policy integration, and public-private sector coordination will ensure the effective implementation of the project, which is important for Georgia's long-term energy security and economic growth.

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ASSESSMENT OF POTENTIAL LIQUID PHASE FORMATION IN NATURAL GAS PIPELINES

Mammadli S.

*pre-doc., student, Oil and Gas Transportation and Storage Department,
Azerbaijan State Oil and Industry University
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Abstract

The formation of liquid hydrocarbons in natural gas pipelines is an important issue affecting the stability and efficiency of gas transportation systems. Even small amounts of condensed liquid can significantly influence flow regimes, pressure behavior, and overall hydraulic performance of pipelines. Therefore, early detection of conditions that may lead to liquid formation is an important task in the analysis of gas pipeline operation.

This study investigates the potential formation of liquid hydrocarbons in a natural gas pipeline using hourly operational data, including pressure, temperature, and gas composition. Particular attention is given to the variation of propane concentration, which represents one of the heavier hydrocarbon components in the gas mixture and has a higher tendency to condense compared to methane and ethane. The analysis focuses on two consecutive days of measurements, considering the identical time interval from 12:00 to 00:00 in order to ensure comparability of the data. The temporal behavior of propane concentration was analyzed and visualized using concentration trend graphs. Additionally, a Hydrocarbon Dew Point Proximity Index was introduced to evaluate the relative closeness of the gas mixture to hydrocarbon condensation conditions. This index provides an indirect indication of the likelihood of liquid phase formation based on variations in the concentration of heavy hydrocarbons.

The results show that during the first analyzed day the propane concentration remained relatively high and stable, indicating a gas mixture richer in heavy hydrocarbons. In contrast, the second day exhibited noticeably lower propane concentrations and greater variability over time. The calculated dew point proximity index demonstrated higher values for the first day, suggesting that the gas mixture was thermodynamically closer to hydrocarbon condensation conditions during this period. The combined analysis of propane concentration trends and the dew point proximity index provides a practical and data-driven approach for identifying potential liquid formation conditions in gas pipelines. The proposed method can be applied for operational monitoring and preliminary diagnostics of multiphase flow risks in natural gas transportation systems.

Annotation

This study investigates the potential formation of liquid hydrocarbons in natural gas pipelines by analyzing hourly variations in gas composition. Temporal trends in heavy component concentrations were used to identify periods where the gas mixture approaches hydrocarbon condensation conditions. The results demonstrate that compositional fluctuations can serve as an effective indicator for assessing the risk of liquid phase formation in pipeline operation.

Keywords: gas pipeline, multiphase flow, propane concentration, liquid hydrocarbon formation

Introduction

Natural gas transmission pipelines are generally designed to transport dry gas under single-phase flow conditions. However, natural gas streams usually contain a certain amount of intermediate and heavy hydrocarbons such as propane, butanes, and pentanes. Under specific thermodynamic conditions, particularly when pressure and temperature approach the condensation region of the mixture, these heavier components may partially condense and form a liquid phase inside the pipeline. The appearance of liquid hydrocarbons in a gas pipeline may significantly influence the hydraulic behavior of the flow, leading to increased pressure losses, changes in flow regimes, and operational instabilities such as slugging, intermittent flow, or liquid accumulation in low sections of the pipeline. [3]

In gas-condensate systems, phase transitions are often associated with the phenomenon of retrograde condensation, where a liquid phase forms as the pressure of the gas mixture decreases at approximately constant temperature. This behavior occurs when the thermodynamic state of the gas approaches the hydrocarbon dew point, which defines the conditions under which the first droplets of liquid hydrocarbons begin to

appear in the gas phase. Accurate prediction and detection of these phase transitions are essential for reliable pipeline operation, since even small quantities of liquid hydrocarbons may alter the flow structure and affect the performance of pipeline equipment such as compressors, separators, and measurement stations. [4]

Direct measurement of liquid hydrocarbon formation within operating pipelines is often difficult because multiphase flow monitoring requires specialized instrumentation and dedicated measurement systems. In many practical situations, pipeline operators rely primarily on standard operational data obtained from flow measurement stations. These data typically include pressure, temperature, gas flow rate, gas density, and detailed gas composition measured using chromatographic analysis. Although these parameters are routinely recorded for operational control and accounting purposes, they can also provide valuable information about the thermodynamic behavior of the transported gas. [2, p.253-260]

Variations in gas composition, particularly in the concentration of intermediate hydrocarbons such as propane, may reflect changes in phase equilibrium within the pipeline system. When a portion of heavier

hydrocarbons condenses into a liquid phase, their concentration in the gas phase may decrease, while the relative fraction of lighter components such as methane increases. Such compositional changes are often accompanied by variations in gas density and may occur simultaneously with changes in operating pressure, temperature, or flow rate. Therefore, analysis of temporal fluctuations in gas composition can potentially provide indirect evidence of phase behavior changes inside the pipeline. [1, p.156-161]

Recent research in pipeline flow monitoring has increasingly focused on the use of operational data for diagnosing abnormal flow conditions and detecting multiphase phenomena. Time-series analysis of pressure, temperature, and gas composition can reveal transient events that may be associated with phase transitions, liquid accumulation, or changes in the thermodynamic equilibrium of the gas mixture. In particular, fluctuations in the concentration of intermediate hydrocarbons may serve as useful indicators of transient thermodynamic processes occurring in the pipeline. [6]

Multiphase flow phenomena represent one of the most significant operational challenges in natural gas transportation systems. The presence of liquid hydrocarbons in gas pipelines can alter the hydrodynamic characteristics of the flow and lead to various operational problems, including pressure fluctuations, liquid accumulation, and changes in flow regime. Even small amounts of condensed hydrocarbons may significantly influence the stability of gas flow and the overall performance of pipeline systems. The formation of liquid phases in natural gas pipelines is therefore closely related to thermodynamic conditions and the concentration of heavier hydrocarbons, which may condense when the gas approaches hydrocarbon dew point conditions. [5]

The present study investigates the relationship between fluctuations in heavy hydrocarbon concentrations and operational parameters in a natural gas pipeline. Hourly monitoring data recorded at a gas measurement station are analyzed, including pressure, temperature, flow rate, gas density, and detailed gas composition. Special attention is given to variations in propane concentration and their correlation with changes in methane content and gas density during the analyzed period.

The objective of this work is to determine whether temporal variations in intermediate hydrocarbon concentrations can provide indications of possible liquid hydrocarbon formation or other phase behavior changes within the pipeline. By examining real operational data from a gas transportation system, this study aims to demonstrate the potential of routine monitoring data for identifying thermodynamic anomalies and improving the understanding of transient processes occurring during gas pipeline operation.

Methodology

The present study is based on the analysis of operational measurements obtained from a natural gas transmission pipeline. The primary objective of the methodological approach is to investigate whether variations in the concentration of heavier hydrocarbon components, particularly propane (C₃), may indicate

thermodynamic processes related to the formation of a liquid phase or redistribution of heavier hydrocarbons within the pipeline system. In gas transmission systems, fluctuations in heavy hydrocarbon concentration can provide indirect information about phase behavior, especially when the gas mixture approaches hydrocarbon dew point conditions.

The dataset used in this study was obtained from a continuous monitoring system installed at a measurement station located along the gas pipeline. The monitoring system records hourly values of several operational parameters, including pressure, temperature, gas flow rate, gas density, and detailed compositional information. Gas composition is measured using an online gas chromatograph, which provides the molar fractions of the principal components of natural gas. These components include methane (C₁), ethane (C₂), propane (C₃), and other heavier hydrocarbons. Continuous compositional monitoring makes it possible to analyze temporal variations in heavy hydrocarbon content and evaluate their potential relationship with thermodynamic conditions in the pipeline. For the purposes of the present investigation, a specific observation window was selected from the available dataset. The analyzed time interval corresponds to the period between 12:00 and 24:00 for two consecutive days. The selection of identical time intervals for both days allows a direct comparison of gas composition behavior under similar operational conditions. Restricting the analysis to this period also reduces the influence of transient operational disturbances and focuses the investigation on gradual compositional variations.

Prior to the analytical stage, the dataset was subjected to a consistency verification procedure. This step included inspection of the recorded measurements for missing values, abrupt discontinuities, or anomalous spikes that could potentially indicate measurement errors. Because the data originate from an industrial pipeline monitoring system, the recorded parameters are assumed to be reliable within the typical accuracy limits of pipeline instrumentation.

The primary parameter investigated in this study is the mole fraction of propane in the gas mixture. Propane represents one of the heavier hydrocarbon components commonly present in natural gas and plays a significant role in the thermodynamic behavior of hydrocarbon mixtures. Compared with lighter components such as methane, propane has a significantly higher tendency to condense under elevated pressure and moderate temperature conditions typical of gas transmission pipelines. The thermodynamic properties of the gas mixture depend strongly on its composition. One of the important characteristics of multicomponent gas mixtures is the average molecular weight. For a gas mixture consisting of several components, the average molecular weight can be determined using the mole-fraction-weighted sum of the molecular weights of individual components:

$$M = \sum_{i=1}^n y_i M_i$$

where M is the average molecular weight of the gas mixture, y_i is the mole fraction of component i , and

M_i is the molecular weight of component i . This relation reflects the fact that heavier hydrocarbons contribute more significantly to the overall molecular characteristics of the gas mixture.

Variations in molecular weight influence the density of natural gas under given thermodynamic conditions. The density of a real gas can be estimated using the real gas equation of state:

$$\rho = \frac{PM}{ZRT}$$

where ρ is the gas density, P is the absolute pressure, M is the molecular weight of the gas mixture, T is the absolute temperature, R is the universal gas constant, and Z is the compressibility factor. The compressibility factor accounts for the deviation of the gas from ideal behavior and depends on both the gas composition and the operating pressure and temperature. In particular, increases in heavy hydrocarbon concentration typically lead to higher molecular weight and higher gas density, which may indicate conditions approaching hydrocarbon saturation.

Although the present study does not involve a full thermodynamic phase equilibrium calculation, these relations provide a theoretical basis for interpreting compositional variations in the gas stream. In particular, increases in heavy hydrocarbon concentration typically lead to higher molecular weight and higher gas density, which may indicate conditions approaching hydrocarbon saturation. To analyze the temporal behavior of heavy hydrocarbons, the measured propane mole fraction values were examined as a time series. Graphical visualization of propane concentration allows the identification of trends and fluctuations over the selected observation period. Time-series analysis provides a practical method for comparing compositional behavior between the two analyzed days.

In addition to direct analysis of propane concentration, the study introduces a qualitative indicator referred to as the Hydrocarbon Dew Point Proximity Index. This index is designed to represent the relative closeness of the gas mixture to hydrocarbon condensation conditions. Because heavier hydrocarbons play a dominant role in determining the hydrocarbon dew point, variations in propane concentration can be used as a simplified indicator of changes in the thermodynamic state of the gas mixture. An increase in propane concentration may indicate enrichment of the gas with heavier hydrocarbons and therefore a shift toward conditions closer to hydrocarbon saturation. Conversely, a

decrease in propane concentration may reflect either dilution of the gas mixture or partial condensation of heavier hydrocarbons in the pipeline.

The temporal behavior of propane concentration and the corresponding dew point proximity index were analyzed using graphical methods. The resulting plots allow a direct comparison of the compositional trends between the two investigated days and provide insight into potential thermodynamic processes occurring within the pipeline.

The final stage of the methodological framework involves the interpretation of observed compositional variations in the context of possible physical mechanisms occurring within the pipeline. Several mechanisms may explain fluctuations in heavy hydrocarbon concentration. One possible explanation is the partial condensation of heavier hydrocarbons when the gas mixture approaches hydrocarbon dew point conditions. In such cases, a fraction of the heavier components may transition into the liquid phase, temporarily reducing their concentration in the gas stream.

Another potential mechanism is the evaporation of previously accumulated liquid hydrocarbons present in the pipeline. If operating conditions change in a way that favors vaporization, part of the liquid phase may return to the gas phase, increasing the measured concentration of heavier hydrocarbons. Additionally, variations in gas composition may occur due to mixing processes within the gas transmission network when gas streams from different sources enter the pipeline system.

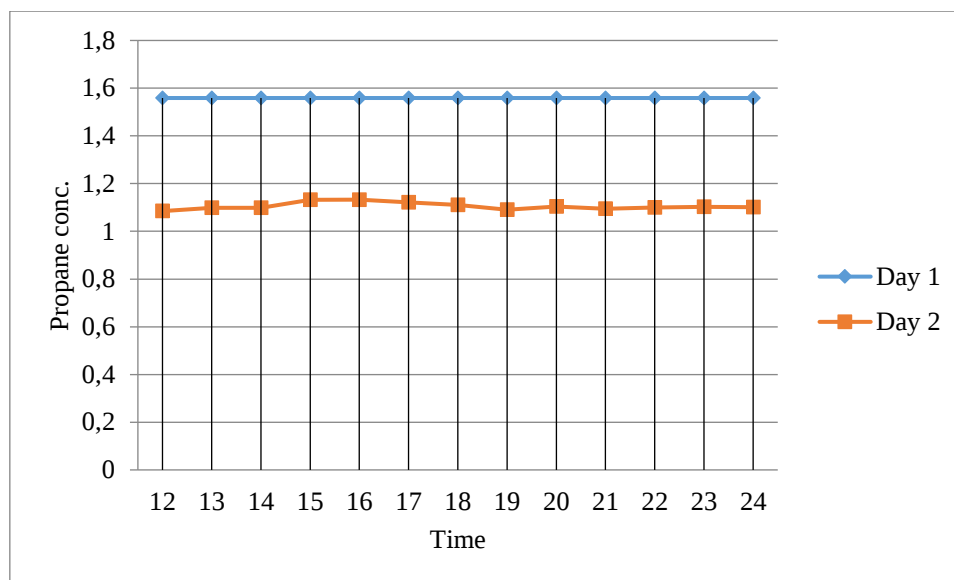
Because the present study is based on measurements obtained at a single monitoring location, it is not possible to uniquely identify the exact mechanism responsible for the observed variations. However, the combined analysis of propane concentration trends and the dew point proximity index provides a practical framework for evaluating the potential risk of liquid hydrocarbon formation in natural gas pipelines.

Results

Hourly measurements of propane mole fraction (C_3) were analyzed for the selected period between 12:00 and 24:00 over two consecutive days. The temporal behavior of propane shows significant fluctuations during the observation interval.

Diagram 1 illustrates the variations of C_3 over time for the two days. Peaks and dips in the propane concentration indicate transient changes in gas composition that may be associated with operational or thermodynamic effects.

Diagram 1



The analysis of heavy hydrocarbon behavior in natural gas pipelines is an important aspect of understanding phase stability during gas transportation. Even small variations in the concentration of heavier components may indicate thermodynamic conditions approaching hydrocarbon condensation. Among the heavier hydrocarbons present in natural gas, propane plays a particularly significant role due to its relatively high molecular weight and stronger tendency to condense compared with methane and ethane. Therefore, monitoring the temporal variation of propane concentration in the gas stream can provide valuable information about the potential formation of liquid hydrocarbons within a pipeline.

In the present study, hourly operational data from a gas pipeline were analyzed in order to investigate possible indications of liquid phase formation. The dataset included measurements of propane concentration, pressure, and temperature. For consistency of analysis, two consecutive days were considered and the same time interval from 12:00 to 00:00 was selected for each day. This allowed a direct comparison of the thermodynamic behavior of the gas mixture under similar operational conditions.

The first stage of the analysis focused on the temporal variation of propane concentration. The graphical representation of propane concentration over time allows identification of possible changes in gas composition and potential thermodynamic transitions in the system. During the first day of observation, the propane concentration remained essentially constant at approximately 1.5588%. The absence of noticeable fluctuations suggests that the composition of the transported gas was stable during that period. Such stability typically indicates a steady operating regime of the pipeline and a consistent composition of the incoming gas stream.

However, the absolute value of propane concentration during the first day was relatively high compared with the values observed during the second day. Since propane is one of the heavier hydrocarbons present in natural gas, a higher concentration of this component increases the overall heaviness of the gas mixture. In thermodynamic terms, this means that the gas

composition moves closer to hydrocarbon dew point conditions. When a gas mixture contains a larger fraction of heavy hydrocarbons, the probability of partial condensation increases, especially if pressure remains relatively high and temperature decreases even slightly.

The second day of observation demonstrates a different behavior of propane concentration. Unlike the nearly constant values observed during the first day, the propane concentration during the second day exhibits moderate variations over time. At the beginning of the analyzed period, the propane concentration was approximately 1.0847%. During the following hours, a gradual increase was observed, reaching a maximum value of approximately 1.1328%. After this peak, the concentration began to decrease again and fluctuated within a range of approximately 1.09–1.10%.

Although these intra-day variations are noticeable, the most important observation is the significant difference between the two analyzed days. The propane concentration during the first day was consistently higher than during the second day. The difference between the average values of propane concentration for the two days is approximately 0.4–0.45 percentage points. From a thermodynamic perspective, this difference is substantial, as heavy hydrocarbon components strongly influence the phase behavior of gas mixtures.

To further evaluate the proximity of the gas mixture to hydrocarbon condensation conditions, a simplified indicator known as the Hydrocarbon Dew Point Proximity Index (HDPI) was introduced. This index provides a practical method for estimating the likelihood of condensation using available operational data. In many practical situations, detailed thermodynamic calculations require complete compositional analysis and advanced equations of state. However, operational monitoring systems often provide only partial compositional data together with pressure and temperature measurements. Under such conditions, simplified indicators can be useful for preliminary diagnostics.

The Hydrocarbon Dew Point Proximity Index was defined as the ratio between the product of propane concentration and pipeline pressure and the absolute gas temperature:

$$HDPI = \frac{C_3 P}{T}$$

where C_3 is the propane concentration in the gas mixture, P is the pipeline pressure, and T is the absolute gas temperature. The physical interpretation of this index is straightforward. Higher concentrations of heavy hydrocarbons increase the probability of condensation. Similarly, higher pressure tends to promote condensation by increasing the density of the gas mixture and moving the thermodynamic state closer to the dew point line. In contrast, higher temperature reduces the probability of condensation by shifting the system further away from phase equilibrium conditions.

Using the measured operational data, the Hydrocarbon Dew Point Proximity Index was calculated for both analyzed days. The results show a clear difference between the thermodynamic conditions of the two periods. During the first day, the index reached significantly higher values due to the elevated propane concentration in the gas mixture. In contrast, the second day was characterized by lower HDPI values because of the reduced concentration of propane, despite the slightly higher pipeline pressure.

The comparison of the calculated index values indicates that the gas mixture during the first day was closer to hydrocarbon dew point conditions than during the second day. This result is consistent with the observed behavior of propane concentration. Since propane represents a heavy hydrocarbon component with a relatively high condensation tendency, its higher concentration increases the probability of liquid hydrocarbon formation in the pipeline flow. Another important aspect supporting this interpretation is the overall density of the gas mixture. The density of natural gas strongly depends on its composition, particularly on the fraction of heavier hydrocarbons. An increase in the concentration of components such as propane, butane, and pentane generally leads to an increase in gas density. Conversely, a reduction in the concentration of heavy hydrocarbons results in a lighter gas mixture with lower density. Therefore, the higher density observed during the first day is consistent with the higher propane concentration and the higher HDPI values calculated for that period.

From a thermodynamic standpoint, these observations suggest that the gas transported during the first day may have been closer to conditions where partial condensation of heavy hydrocarbons becomes possible. Although the available data do not allow a full phase equilibrium calculation, the combination of higher propane concentration and higher dew point proximity index indicates that the probability of liquid hydrocarbon

formation was greater during the first day of observation. The graphical analysis of propane concentration combined with the calculated dew point proximity index therefore provides a useful diagnostic approach for identifying potential condensation risks in gas pipelines. Such methods are particularly valuable in operational environments where complete thermodynamic characterization of the gas mixture is not available in real time. By continuously monitoring heavy hydrocarbon concentrations and evaluating simplified thermodynamic indicators, pipeline operators can identify periods when the gas mixture approaches hydrocarbon dew point conditions and take preventive measures if necessary.

In summary, the analysis of hourly operational data revealed a clear difference in the thermodynamic behavior of the gas mixture between the two analyzed days. The first day was characterized by a higher and stable propane concentration, which resulted in higher values of the Hydrocarbon Dew Point Proximity Index. These conditions indicate a gas mixture richer in heavy hydrocarbons and therefore closer to hydrocarbon condensation conditions. In contrast, the second day exhibited lower propane concentrations and lower index values, suggesting that the gas mixture was thermodynamically further from the dew point. The combined use of propane concentration trends and the dew point proximity index therefore provides a practical method for assessing the potential risk of liquid hydrocarbon formation in natural gas pipelines.

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DEVELOPMENT OF THE INFORMATION SYSTEM OF CONTROL OF QUALITY OF THE INDUSTRIAL GOODS**Ovcharuk V.***PhD, Docent, Associate Professor of the Department of Information Technology, Artificial Intelligence and Cyber security, National University of Food Technologies, Kyiv, Ukraine***ПРОЄКТУВАННЯ ІНФОРМАЦІЙНОЇ СИСТЕМИ МОНІТОРИНГУ ТА ЗАБЕЗПЕЧЕННЯ ЯКОСТІ ПРОДУКЦІЇ****Овчарук В.***К.т.н., доцент, доцент кафедри інформаційних технологій, штучного інтелекту і кібербезпеки, Національний університет харчових технологій, Київ, Україна*<https://doi.org/10.5281/zenodo.19050771>**Abstract**

There is offered the technique of the automated coding of products at the stages of their life cycle, providing identification of the processes of products manufacture and occurrence of defects. The technique enables to predict already at the stage of manufacture preparation the causes of defects occurrence and provides the complex system of monitoring and control of products quality parameters.

Анотація

Запропонована методика автоматизованого кодування виробів на етапах їх життєвого циклу, що забезпечує ідентифікацію процесів виробництва виробів та виникнення дефектів. Методика дозволяє вже на етапі підготовки виробництва прогнозувати причини виникнення дефектів та забезпечує комплексну систему контролю та управління показниками якості продукції.

Keywords: method, system of control quality, information, cod of product, life of cycle.**Ключові слова:** метод, система контролю якості, інформація, код товару, життєвий цикл.

Необхідною умовою входження України у світову економіку є наявність на машинобудівних підприємствах сучасних систем керування якістю продукції. При виході на міжнародний ринок ця система повинна

відповідати стандартам ISO 9000:2000.

У цей час питання сертифікації продукції вітчизняного машинобудування в межах цих стандартів стає дуже актуальною проблемою.

Загальні вимоги до системи якості, які необхідно реалізувати у вигляді конкретних документованих процедур, адаптованих до конкретного підприємства, існують у форматі зазначених міжнародних стандартів, а також у рамках CALS-технологій. CALS (Continuous Acquisition and Life cycle Support) – технології забезпечують безперервний розвиток і підтримку життєвого циклу виробів. Основним завданням CALS-технологій є перетворення життєвого циклу (ЖЦ) виробу в автоматизований процес шляхом реструктуризації вхідних у нього процесів на базі сучасних інформаційних технологій: автоматизації проектування; автоматизації керування виробничим процесом; створення єдиного інформаційного простору про виріб на всіх етапах його ЖЦ [2].

У зв'язку з організаційно-технічними і фінансовими труднощами впровадження систем контролю якості, доцільні поетапна розробка й реалізація цієї системи з урахуванням досвіду передових підприємств провідних галузей машинобудування [3].

Початком рішення завдань є аналіз існуючих на виробництві технологічних, організаційних,

управлінських основ. За рубежом ця галузь, що активно розвивається, називається технологічним аналізом і реінжинірингом.

Такий аналіз розкриває майже всі проблеми підприємства, з урахуванням яких будується функціональна модель виробництва.

При цьому:

- вказуються першочергові й загальні раціональні напрямки дії, включаючи удосконалювання організаційної й технологічної структури;
- розглядаються основні процеси, що визначають якість продукції, що випускається, або аналізуються процеси, що забезпечують створення нового виробу, розробку його основ, підтримку і забезпечення ЖЦ;
- формується уява про найкращі варіанти реалізації пропонованого проекту.

Інформацію й документи, що циркулюють у системі керування якістю продукції, не важко представити у вигляді інформаційної моделі, що містить логічну модель бази даних про якість. Прикладом може служити система TQM (Total Quality Management), використовуючи яку простежують вплив на якість виробу всіх об'єктів функціонування підприємства [4]. Це, у свою чергу, дозволяє проаналізувати модель забезпечення якості, досконально розібратися в матеріальних і інформаційних потоках, уточнити дії автоматизованої системи обробки даних і керування підсистемами якості продукції.

З метою підвищення якості продукції необхідно виявлення не тільки дефектів, але і їхніх першопричин. Лише при виконанні цієї умови з'явиться можливість коректування дій. Для визна-

чення причини появи того або іншого дефекту конкретного виробу потрібно виявити місце його виникнення на етапах ЖЦ виробу. Ці етапи представляються як сукупність операцій, на кожній з яких змінюються значення показників якості продукції.

Аналіз дефектів показав, що їх можна класифікувати по складових елементах виробу – вузлам і деталям, а для кожного вузла й деталі – за ознаками, зв'язним з конкретним тимчасовим інтервалом і етапом ЖЦ, наприклад, конструкторського або технологічного проектування, виробництва або транспортування. За кожний етап повинен відповідати певний фахівець, код якого враховується при формуванні відповідної інформації.

Для машинобудівного підприємства дуже важлива інформація про функціонування продукції, що випускається, у період експлуатації, така інформація в цей час приходить у вигляді рекламаций.

Форма рекламацийного акту така, що заповнена рекламація не дає вичерпної інформації про несправності. Одержавши подібну рекламацію, неможливо сформулювати коригувальні дії.

Для визначення причини появи того або іншого дефекту у виробі в рамках єдиної інформаційної автоматизованої системи керування підприємством забезпечується встановлення першопричини дефекту і їхнього місцезнаходження за допомогою ідентифікаційних кодів. Будь-який виріб можна представити як матеріальний потік зовнішніх факторів, що змінюється в часі під впливом, (механічний, хімічний вплив, зборка й т.д.). Відповідно, і кодифікатор виробу повинен бути змінним у часі.

Найбільше повно задовольняють вимогам підтримки єдиної інформаційної системи контролю виробу стандарти, використовувані в авіабудуванні, тому за основу візьмемо існуючий кодифікатор, пропозицій стандартом АЕСМА 1000 D. Суть підходу полягають у тім, що технічна інформація, що міститься в документації, представляється у вигляді сукупності так званих модулів даних (МД).

Будь-якому модулю МД, що входить до складу технічної документації, привласнюється унікальний код. До складу коду, як правило, входять наступні поля:

- умовна позначка типу виробу;
- код конфігурації виробу (у випадку, коли можливий випуск виробу в різних конфігураціях, це поле вказує, для якої конфігурації застосовується вказаний МД);
- код стандартної системи нумерації;
- інформаційний код, що однозначно ідентифікує, до якого типу технічних даних відноситься інформація в МД.

Крім відповідних кодових номерів, привласнених конструкторським кресленням деталей, вузлів і готових виробів, необхідно на етапі конструкторської підготовки виробництва ввести в базу даних коди структурних елементів виробу (рис.1), тому що виріб складається з вузлів і деталей, і виникненні дефектів можливо на різних етапах при формуванні певних поверхонь деталей або при зборці.

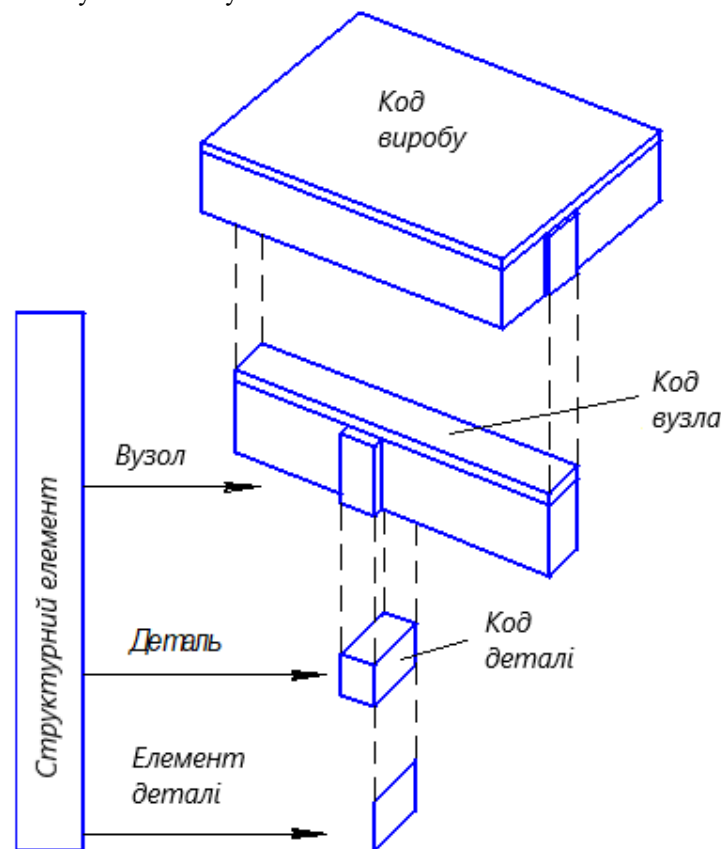


Рис.1. Складові елементи виробу

Відповідно до методики формування коду розроблена матриця, в клітинках якої, що відповідають етапам виготовлення виробу і його структурних елементів, формується код. У базу даних необхідно увести інформацію про партії заготовок, деталей, вузлів або виробів, вимоги до якості. На будь-якому етапі за номером партії з бази даних при необхідності можна простежити весь життєвий цикл виробу.

Для будь-якої системи визначаючим є її функціональний зміст. Для побудови функціональної

моделі [4] формування коду виробу на етапі ЖЦ необхідно провести всебічний аналіз складових процесів, структур і функцій ЖЦ, а також їхнього оточення на основі об'єктивної формалізації.

Відзначимо, що саме оточення визначає основні характеристики й порядок функціонування будь-якої системи. Типове формалізоване інформаційне оточення представлено на рис. 2.

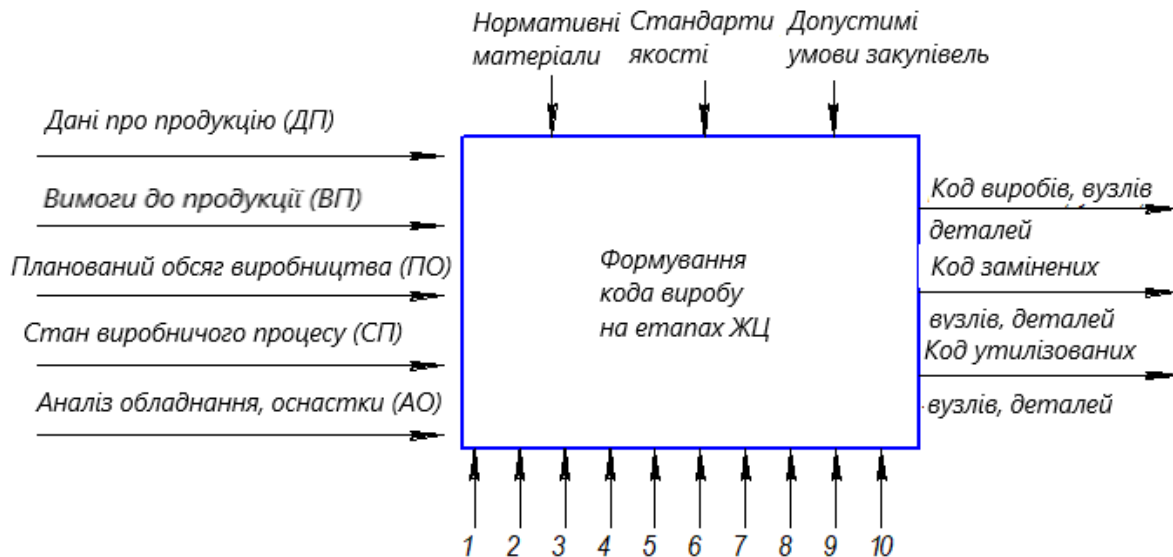


Рис. 2. Формування коду виробу на етапах ЖЦ:

1, 2, 3, 4 – відділи: методів обробки замовлень, підготовки виробництва, конструкторський, техніко-логічний; 5 – нормоконтроль; 6, 7, 8 – цехи: заготівельний, механообробки, складальний; 9 – склад; 10 – сервісна служба.

Код виробу формується поетапно відповідно до функціональної моделі (рис.3). Наприклад, на етапі експлуатації при сервісному обслуговуванні код формується на основі заявки на обслуговування, при цьому вносяться коди заміненних або утилізованих вузлів, деталей.

Далі перевіряється, чи перебуває виріб на гарантії. При виконанні цієї умови заповнюються поля таблиці реклаमाції.

Незалежно від того, чи є споживач зовнішнім або внутрішнім, перебуває виріб на гарантії чи ні, відбувається визначення дефекту за його діагностичною ознакою. Після цього дефект реєструється, визначаються етап ЖЦ і операція, де було допущене порушення, у результаті якого виник дефект.

При цьому в циклі виконується перевірка на порушення нормативних вимог послідовно на кожному з етапів ЖЦ виробу.

При виявленні етапу, на якому відбулося порушення, реєструється причина виникнення дефекту

(автоматично заповнюється відповідне поле таблиці), після чого аналогічним чином визначаються операції на даному етапі ЖЦ, на яких міг виникнути дефект, а також пропонують коригувальні й попереджувальні заходи. Аналогічно перевіряються порушення нормативних вимог на кожній операції. Після завершення всіх перевірок виводиться список тих етапів життєвого циклу й операції, на яких не були виконані вимоги.

Після цього проводиться обробка збереженої інформації, формуються й виводяться звіти.

Висновок. Розроблена функціональна модель життєвого циклу виробів забезпечує комплексну систему контролю і керування показниками якості продукції на основі кодування інформації про об'єкт-виріб і ідентифікацію ознак дефектів та дозволяє організувати систему збору й обробки даних для підвищення оперативності і якості застосовуваних рішень.

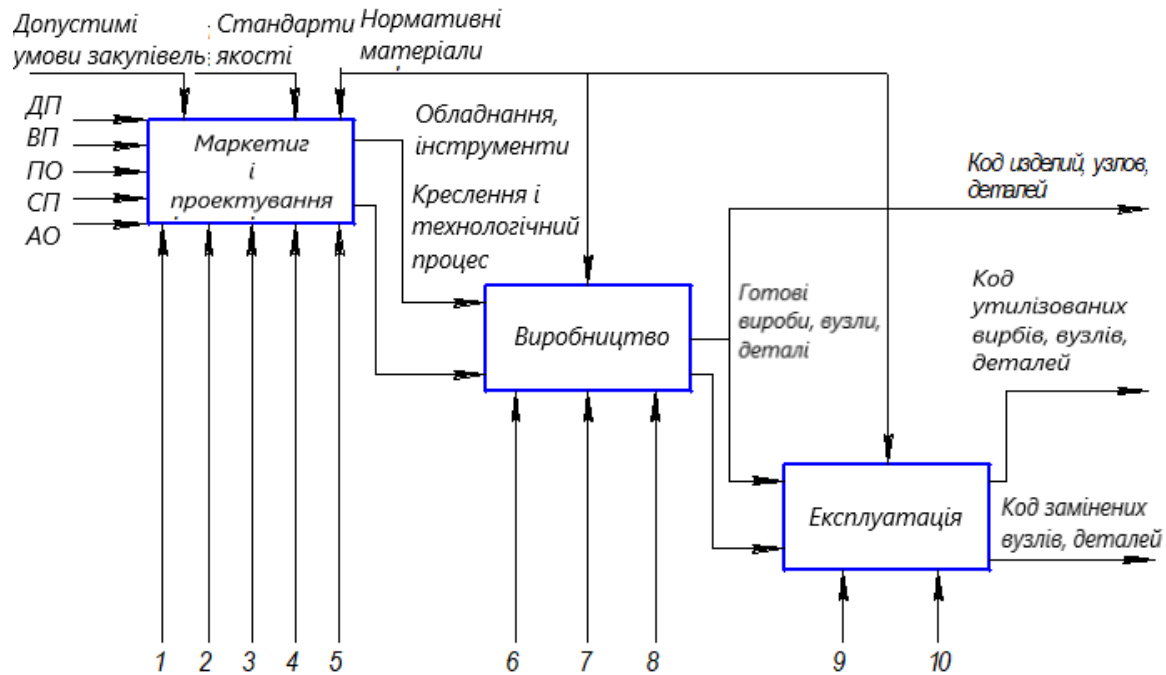


Рис.3. Функціональна модель формування коду виробу: поз. 1 – 10 див. рис.2.

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