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CHEMISTRY

РАЗРАБОТКА ТЕХНОЛОГИИ ПОЛУЧЕНИЯ ИММУНОСТИМУЛИРУЮЩЕГО СУХОГО ЭКСТРАКТА «ИММУНОКОР» НА ОСНОВЕ ПОЛИСАХАРИДОВ ИЗ НАДЗЕМНОЙ ЧАСТИ *Bidens tripartita* МЕТОДОМ РАСПЫЛИТЕЛЬНОЙ СУШКИ

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DEVELOPMENT OF A SPRAY DRYING TECHNOLOGY FOR PRODUCING THE IMMUNOSTIMULATORY DRY EXTRACT "IMMUNOKOR" BASED ON POLYSACCHARIDES FROM THE AERIAL PARTS OF *Bidens tripartita*

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Аннотация

В статье представлены результаты оптимизации процесса получения сухого экстракта «Иммунокор» из надземной части (н/ч) череды трехраздельной (*Bidens tripartita* L.) методом распылительной сушки. Выявлено, что сушка водного экстракта н/ч *Bidens tripartita* в распылительной сушилке является оптимальной по сравнению с сушкой в сушильном шкафу, обеспечивая лучшие органолептические характеристики, минимальное время процесса (1 ч на обработку 1 кг сырья). При этом для сушки в распылительной сушилке высушиваемый водный экстракт необходимо подготовить следующим образом: после экстракции и фильтрации сумму полисахаридов концентрируют в вакуум-выпарном аппарате при 60–70 °С и вакууме 0,04–0,08 МПа до содержания сухого остатка 15 %. Установлено, что для получения готового продукта стабильного по выходу и качеству сушку водного экстракта полисахаридов в распылительной сушилке нужно осуществлять при температуре теплоносителя на входе 180–190 °С, на выходе 85–90 °С, давлении воздуха на форсунку 0,2 МПа, со скоростью подачи раствора 5 л/ч (5,5 л/ч·м³). Разработана технология производства субстанции «Иммунокор экстракт сухой» из н/ч *Bidens tripartita* с иммуностимулирующим действием, позволяющая получить продукт с содержанием полисахаридов не менее 15 %. Апробация разработанной технологии показала, что выход целевого продукта составляет 12,2 % от массы сырья.

Abstract

The article presents the optimization of the process for obtaining the dry extract "Immunokor" from the aerial parts of *Bidens tripartita* L. using spray drying. It was found that drying the aqueous extract of the aerial parts of *B. tripartita* in a spray dryer is optimal compared to drying in a drying cabinet, providing better organoleptic characteristics, minimal process time (1 hour per 1 kg of raw material). For drying in the spray dryer, the aqueous extract to be dried should be prepared as follows: after extraction and filtration, the polysaccharide sum is concentrated in a vacuum evaporator at 60–70 °C and vacuum of 0.04–0.08 MPa to a dry residue content of 15%. It was established that to obtain a finished product stable in yield and quality, drying of the aqueous polysaccharide

extract in the spray dryer should be carried out at an inlet heat carrier temperature of 180–190 °C, outlet temperature of 85–90 °C, solution feed rate of 5 L/h (5.5 L/h·m³), and air pressure on the nozzle of 0.2 MPa. A technology has been developed for producing the substance "Immunokor dry extract" from the aerial parts of *B. tripartita* with immunostimulatory action, which allows obtaining a product with a polysaccharide content of at least 15%. Pilot testing of the developed technology showed that the yield of the target product is 12.2% of the raw material mass.

Ключевые слова: *Bidens tripartita*, полисахариды, сухой экстракт, распылительная сушка, технология, иммуностимулирующее действие.

Keywords: *Bidens tripartita*, polysaccharides, dry extract, spray drying, technology, immunostimulating effect.

Введение

Bidentis tripartitae L. (Черёда трехраздельная; семейства сложноцветные (*Asteraceae*)) – однолетнее травянистое растение, произрастающее по всему Узбекистану [1]. Надземная часть (н/ч) *B. tripartitae* содержит эфирное масло, флавоноиды, кумарины, дубильные вещества, полиацетилены, каротин и витамин С, а также горечи, слизи и лактоны [2-4]. В эфирном масле, выделенном из н/ч череды трехраздельной, определены такие вещества, как алло-оцимен, (Z)- β-оцимен, α-фелландрен – [5, 6]. С помощью масла выделены α-пинен, β-бисаболен, п-цимен, гексанал, линалоол, п-цимен-9-ол, β-элемен, 2-пентифуран, силфиперфол-6-ен – [7]. В состав компонентов н/ч *B. tripartitae*, также входят минеральные соли Zn, Se, Mn, Cd [8, 9]. В н/ч *B. tripartitae* из флавоноидов, в основном, содержатся лютеолин, цинарозид, ассоциированные халконы: бутеин, бутеин-7-О-β-D-глюкопиранозид и мареин, флавононы: изокореопсин и флаваномареин, ауроны: сульфуретин, сульфуреин, маритиметин, маритимеин [10-12]. Из кумаринов в н/ч *B. tripartitae* содержатся умбеллиферон, скополетин, эскулетин, тридекан-производные полиацетиленов: тридека-1,12-диен-3,5,7,9-тетраин, лютеин. Из н/ч *B. tripartitae* выделены водорастворимые полисахариды (до 10%), пектиновые вещества (до 1,0%) и гемицеллюлозы А и Б (до 3,0% и 0,6% соответственно). Во фракционном составе водорастворимых полисахаридов основными моносахаридами являются глюкоза, галактоза, глюкуроновая и галактуроновая кислоты [13]. Показано, что в н/ч *B. tripartitae*, произрастающей в Узбекистане, содержится около 5% полисахаридов, состоящих, в основном, из моносахаридов, таких как галактоза, глюкоза, арабиноза, ксилоза и уруновая кислота [14].

Траву череды в виде настоя и лечебных ванн применяют в педиатрии при диатезах, скрофулезе (золотухе); как противовоспалительное, потогонное и мочегонное средство при простудных заболеваниях. Спиртовые экстракты имеют противоаллергический и желчегонный эффект. Травя череды входит в состав потогонных и мочегонных сборов [15]. В качестве гипогликемического и антидиабетического средств предложены настойки н/ч *B. tripartitae* [8]. Показано седативное и гипотензивное действие 20%-ной настойки череды [16]. Авторами [17, 18] показаны адаптогенная, антиоксидантная, противовоспалительная активность и болеутоляющие свойства экстрактов, полученных из н/ч *B. tripartitae*. Установлено благоприятное влияние суммарных фракций череды трехраздельной на ге-

модинамику нормотензивных крыс. При этом доказаны гипотензивные свойства спиртовых экстрактов череды [19]. При изучении различных образцов экстрактов, выявлены выраженные гепатопротекторные свойства фракций, обогащенных флавоноидами [20]. Показано, что мазь, приготовленная из сухого экстракта травы и вазелина, при наружном применении лечит псориаз. Наружное применение препаратов череды успокаивает зуд, оказывает противоаллергическое действие. Флавоноиды череды уменьшают количество гистамина при экспериментальной аллергии [25]. Экспериментальные исследования показали, что настойка травы череды приводит к быстрому очищению и заживанию инфицированной костно-мышечной раны [22]. Изучены иммуностимулирующие свойства жидкого экстракта *B. tripartitae*, которые не уступают по эффективности препарату иммунал при коррекции иммунодефицитных состояний [23, 24]. Н/ч *B. tripartitae* оказывает противовоспалительное и антибактериальное действие против патогенных бактерий, таких как *Staphylococcus aureus*, *Escherichia coli*, *Proteus vulgaris* [25, 26].

Вышеизложенное показывает, что *B. tripartitae* богата биологически активными веществами различного класса, проявляющими различную фармакологическую активность растения или препаратов, полученных из *B. tripartitae*. Литературный обзор по применению н/ч *B. tripartitae* и собственные исследования показывают, что противоаллергические свойства проявляют флавоноиды [27, 28], а иммуностимулирующие свойства – полисахариды [24]. Из вышеизложенного видно, что многие исследования фармакологических свойств *B. tripartitae* проведены на экстрактах, содержащих флавоноиды и полисахариды. Поэтому экстракты, полученные этиловым спиртом в различных концентрациях, проявляют противоаллергические и иммуностимулирующие свойства.

Учитывая вышеизложенное, нами для лечения аллергических заболеваний предложена сумма флавоноидов, которая обладает именно противоаллергическим эффектом, а в качестве иммуностимулирующего средства – предложена сумма полисахаридов. В результате совместных исследований Института химии растительных веществ (ИХРВ) и Института иммунологии и геномики человека АН РУз на основе флавоноидов н/ч *B. tripartitae* создан новый оригинальный препарат антигистаминного и противоаллергического действия «Аллергодаф», а также иммуностимулирующий препарат «Иммунокор» на основе полисахаридов [24, 27-31].

Целью исследования является разработка оптимальной технологии сушки водного экстракта полисахаридов из н/ч *B. tripartitae* для получения субстанции «Иммунокор экстракт сухой» с иммуностимулирующей активностью.

Материалы и методы исследований

Используемая н/ч *B. tripartitae* в экспериментах обладала следующими характеристиками: содержание полисахаридов не менее 3,5 %; содержание суммы флавоноидов (в пересчете на лютеолин-стандарт) не менее 0,5 %; влажность не более 13 % (ГФ XI, вып. 1, с. 285); зола общая не более 14 % (ГФ XI, вып. 2, с. 24); зола, нерастворимая в 10 %-ном растворе хлористоводородной кислоты, не более 2 % (ГФ XI, вып. 2, с. 25); частиц, не проходящих сквозь сито с отверстиями диаметром 7 мм, не более 10 % (ГФ XI, вып. 1, с. 275); частиц, проходящих сквозь сито с размером отверстий 0,5 мм, не более 15 % (ГФ XI, вып. 1, с. 276); органической примеси не более 3 % (ГФ XI, вып. 1, с. 276); минеральной примеси не более 1 % (ГФ XI, вып. 1, с. 276).

Содержание сухих остатков водных экстрактов (водорастворимых веществ) определяли на рефрактометре. Относительная ошибка единичного определения составляет $\pm 5\%$.

Определение влажности субстанции «Иммунокор экстракт сухой» проводили следующим образом: точную навеску образца субстанции помещали в предварительно высушенный и взвешенный бюкс и сушили при температуре 105 °С. Бюкс с высушенной пробой помещали в эксикатор для охлаждения на 50 мин, затем взвешивали. Первое взвешивание проводили после сушки в течение 2 ч. Последующие взвешивания проводили после каждого часа дальнейшего высушивания. Процесс повторяли до постоянной массы образца субстанции. Массовую долю сухого остатка (в %) вычисляли по формуле 1:

$$W = \frac{m_2 - m_1}{m} * 100; \quad (1)$$

где: m – навеска, г; m_1 – масса чаши, г; m_2 – масса чаши с остатком после высушивания, г.

Как ранее сообщалось, водный экстракт полисахаридов, полученный при температуре 70 °С, обладает способностью в 1,53–2,32 раза повышать иммунный ответ к эритроцитам барана у мышей с полноценной иммунной системой [24]. Учитывая это, при проведении экспериментов проводили экстракцию водой при температуре 70 °С и далее экстракт сушили на различных установках, основываясь на методиках, описанных в [32–34].

Для подбора типа сушильного аппарата нами проведен ряд экспериментов. Для этого по 1,0 кг воздушно сухого сырья загружали в пять экстракторов, где его трехкратно экстрагировали водой при температуре 70 °С. Объединенный и отфильтрованный первый экстракт сгущали до густой массы и сушили в вакуумно-сушильном шкафу марки «ШСВ-45К» (Россия) при температуре 70–80 °С и вакууме 0,6–0,8 кгс/см² (образец 1). Второй сгущенный экстракт сушили в сушилке инфракрас-

ного излучения марки «ИКС-2М» (Россия) при температуре 70 °С (образец 2). Экстракты из третьего экстрактора также объединяли, отфильтровывали, затем концентрировали до содержания сухой массы в экстракте 10%. Концентрат сушили в распылительной сушилке форсунчатого типа «Anhydro No. 2» (Дания), температура теплоносителя при входе 180 °С, на выходе 90 °С, давление воздуха для распыления раствора 0,15 МПа (образец 3). Полученные сухие экстракты измельчали в мельнице и просеивали через сито с отверстиями 0,5 мм.

Для изучения влияния температуры на процесс сушки полисахаридов из н/ч *B. tripartitae* эксперименты проводили следующим образом: 6,0 кг воздушно сухой н/ч *B. tripartitae* загружали в экстрактор и трехкратно экстрагировали водой при температуре 70 °С. Объединенный и отфильтрованный экстракт концентрировали до содержания 10% сухой массы в экстракте. Концентрат разделили на шесть частей и сушили в распылительной сушилке при различной температуре, при скорости подачи раствора 4,0 л/ч.

Эксперименты по подбору скорости подачи раствора на процесс сушки полисахаридов из н/ч *B. tripartitae* проводили следующим образом: 5,0 кг сырья загружали в экстрактор, где трехкратно экстрагировали водой при температуре 70 °С. Объединенный и отфильтрованный экстракт концентрировали до содержания 10% сухой массы в экстракте. Концентрат разделили на пять частей и сушили в распылительной сушилке при температуре теплоносителя на входе 190 °С, выходе 90 °С, при различных скоростях подачи раствора.

Выбор концентрации высушиваемого раствора при сушке полисахаридов из н/ч *B. tripartitae* осуществляли по следующей методик: воздушно сухую н/ч *B. tripartitae* по 1,0 кг загружали в пять экстракторов. Затем полисахариды экстрагировали трехкратно водой при температуре 70 °С. Полученные экстракты объединяли и отфильтровывали. Экстракт из первого экстрактора с содержанием 5% сухого остатка сушили в распылительной сушилке при температуре теплоносителя на входе 190 °С, выходе 90 °С, при скорости подачи раствора 5 л/ч. Экстракт из второго экстрактора концентрировали до 10% сухого остатка, из третьего экстрактора – до 15%, из четвертого – до 20% и из пятого – до 25%. Концентраты сушили в распылительной сушилке в режиме, описанном при сушке экстракта из первого экстрактора.

Для исследования влияния давления воздуха, подаваемого на форсунку распылителя, на качество субстанции «Иммунокор экстракт сухой», 5,0 кг воздушно сухой н/ч череды трехраздельной загружали в экстрактор, где полисахариды экстрагировали трехкратно водой при температуре 70 °С. Полученные экстракты объединяли, отфильтровали и концентрировали до содержания сухого остатка 15%. Концентрат разделили на 5 порций и каждую сушили в распылительной сушилке при температуре теплоносителя на входе 190 °С, выходе 90 °С, при скорости подачи раствора 5 л/ч, при различном

значении давления воздуха, подаваемого на форсунку распылителя.

Результаты и обсуждение

Изучение процесса сушки водного экстракта *n/ч B. tripartitae* показало, что образцы 1 и 2 представляют собой твердые массы, которые с противня сушилки трудно отделялись и прилипали к ножу

мельницы при измельчении. При сушке в распылительной сушилке потери продукта больше на 9,0 %, чем при сушке в остальных типах сушилок. Учитывая, что выход субстанции «Иммунокор экстракт сухой» почти одинаков, по органолептическим характеристикам и расходу времени для сушки водного экстракта *n/ч B. tripartitae* выбрали распылительную сушилку (табл. 1).

Таблица 1

Влияние типа сушки на выход и биологическую активность полисахаридов из *n/ч B. tripartitae*

№ образца субстанции	Выход субстанции «Иммунокор экстракт сухой», % к массе сырья	Расход времени для процесса сушки, ч	Количество субстанции, не проходящее через сито, в % к сухому экстракту
1	3,95	12,0	8,40
2	3,92	10,5	6,20
3	3,75	1,0	0,00

С целью установления оптимальных режимов сушки, обеспечивающих требуемое качество конечного продукта, мы изучили следующие параметры: концентрацию раствора; скорость подачи раствора; температуру сушильного агента на входе и выходе; давление при подаче раствора в сушильную камеру. Максимальная производительность сушилки с объемом сушильной камеры 0,9 м³ и мощностью электрокалорифера 9 кВт составляет 5 кг/ч по испаренной влаге при сушке чистой воды.

Результаты экспериментов по изучению влия-

ния температуры на процесс сушки продемонстрировали, что повышение температуры теплоносителя на входе в сушильную камеру сопровождается ростом производительности сушки и снижением влажности готового продукта. При сушке с температурой теплоносителя на входе 180–190 °С и на выходе 85–90 °С экстракт не успевает полностью высохнуть, в результате чего часть продукта прилипает к стенкам камеры сушилки. Кроме того, полученный в сборнике продукт имеет пластилинобразную консистенцию (табл. 2).

Таблица 2

Влияние температуры сушки на качество субстанции «Иммунокор экстракт сухой»

Температура теплоносителя, °С		Влажность конечного про- дукта, %	Выход субстанции «Имму- нокор экстракт сухой», % к массе сырья
на входе	на выходе		
150	65	20% продукта прилипало к стенке сушилки	
160	70	15% продукта прилипало к стенке сушилки	
170	75	8,0	3,6
180	85	5,8	3,8
190	90	3,6	3,7
200	95	2,3	1,9

Продукт, высушенный при температуре теплоносителя на входе 170 °С и на выходе 75 °С, не соответствует требованиям к влажности сухих экстрактов. Повышение температуры теплоносителя на входе выше 190 °С приводит к ухудшению органолептических характеристик сухого продукта: появляется посторонний запах, ухудшаются вкус и цвет, в целом снижаются потребительские качества. При этом возрастают потери продукта из-за образования чрезмерно мелких частиц (табл. 2).

Удовлетворительные результаты достигнуты при температуре теплоносителя на входе 180–190 °С и на выходе 85–90 °С (табл. 2).

Скорость подачи высушиваемого раствора играет большую роль при сушке в распылительной

сушилке. Это объясняется тем, что быстрая подача раствора приводит к увеличению влаги в готовом продукте, а в обратном случае увеличивается потеря продукта за счет образования слишком мелких частиц и затраты времени. В связи с этим изучена скорость подачи раствора, результаты которой приведены в табл. 3.

Из табл. 3 видно, что при скорости подачи более 6 л/ч раствор плохо высушивается и часть экстракта прилипает к стенкам камеры сушилки, а также влажность конечного продукта превышает допустимую норму. При скорости менее 4 л/ч снижается выход конечного продукта. Поэтому для производства субстанции «Иммунокор экстракт сухой» выбрана скорость подачи раствора – 5 л/ч (5,5 л/ч*м³).

Таблица 3

Влияние скорости подачи раствора на качество субстанции «Иммунокор экстракт сухой»

Скорость подачи раствора, л/ч	Влажность конечного продукта, %	Выход субстанции «Иммунокор экстракт сухой», % к массе сырья
2	1,5	3,1
3	2,1	3,2
4	3,2	3,5
5	3,6	3,7
6	10% продукта прилипло к стенке сушилки	

Эффективность эксплуатации сушилки во многом зависит от правильного выбора концентрации высушиваемого раствора, так как это влияет на производительность сушилки и энергопотребление на единицу высушенного продукта. Результаты исследований по подбору оптимальной концентрации высушиваемого раствора показали, что сушка неконцентрированного водного экстракта из н/ч *B. tripartitae* не соответствует по массовой доле влажности конечного продукта. Кроме того, в процессе сушки часть готового продукта (около 3-4%) прилипла к стенке камеры распылительной сушилки.

При сушке концентрата с содержанием сухого остатка более 15% выход готового продукта уменьшается, и цвет получаемой субстанции темнеет. Удовлетворительный результат получили при сушке раствора с содержанием сухого остатка 10-15%. Однако при сушке 10% концентрата расход времени и энергии больше, по сравнению сушки 15% концентрата. Исходя из этого, пришли к выводу, что для сушки водного экстракта необходимо концентрировать его до значения сухого остатка 15% (табл. 4).

Таблица 4

Влияние концентрации раствора на качество субстанции «Иммунокор экстракт сухой»

Концентрация высушиваемого раствора, % сухого остатка	Влажность субстанции «Иммунокор экстракт сухой», %	Выход субстанции «Иммунокор экстракт сухой», % к массе сырья	Цвет субстанции «Иммунокор экстракт сухой»
5	6,2	3,5	Светло коричневый
10	3,8	3,7	Коричневый
15	2,4	3,7	Коричневый
20	2,0	3,6	Темно коричневый
25	1,7	3,5	Темно коричневый

Степень распыления раствора форсункой в сушильной камере зависит от давления воздуха, подаваемого на форсунку распылителя. Оптимальное давление обеспечивает хорошую высушиваемость раствора в камере. В связи с этим, нами проведен ряд экспериментов по подбору давления воздуха, подаваемого на форсунку распылителя, для сушки полисахаридов из н/ч *B. tripartitae*. Полученные результаты приведены в табл. 5.

Исходя из данных, приведенных в табл. 5, оптимальное давление подаваемого воздуха в форсунку – 0,2 МПа. При давлениях 0,05; 0,1; 0,15 МПа раствор плохо распылялся внутри сушилки, и получаемый продукт был влажным. Кроме того, при давлении 0,05 МПа около 10-12% экстракта прилипло на дно камеры распылительной сушилки. При 0,25 МПа раствор прилипал к верхней стенке сушилки.

Таблица 5

Влияние давления воздуха, подаваемого на форсунку распылителя, на качество субстанции «Иммунокор экстракт сухой»

Давление воздуха, МПа	Влажность конечного продукта, %	Выход субстанции, % к массе сырья
0,05	6,1	3,5
0,10	5,5	3,7
0,15	2,5	3,7
0,20	1,9	3,6
0,25	1,8	3,1

На основе полученных результатов разработана технология получения субстанции «Иммунокор экстракт сухой» из н/ч череды трехраздельной

(рис. 1).

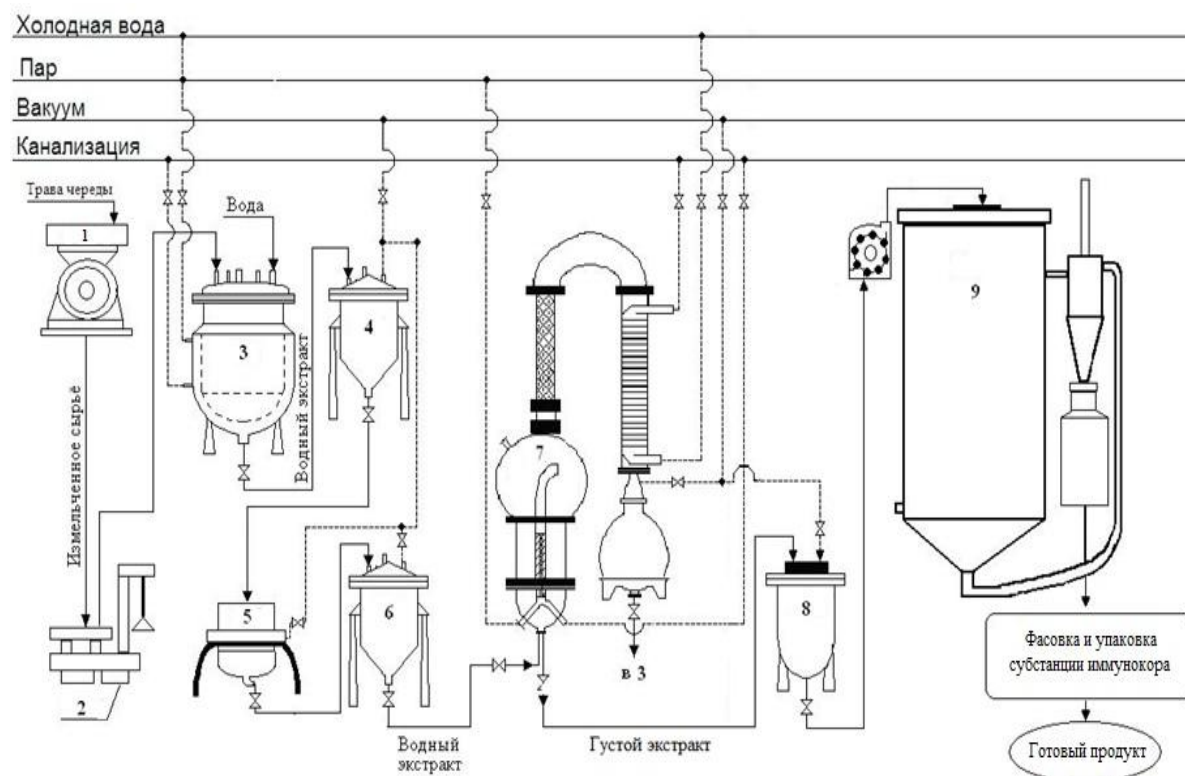


Рис. 1. Аппаратурная схема производства субстанции «Иммунокор экстракт сухой»

Воздушно-сухую надземную часть череды трехраздельной взвешивают на весах (2) в количестве 52,5 кг, измельчают на молотковой мельнице (1) до степени измельчения сырья 6 мм. Измельченное сырьё в количестве 50 кг затаривают вручную в мешки и вручную загружают в экстрактор (3) и заливают 250,0 л воды. Экстрагируют при температуре 60–70°C в течение 2 часов. После экстракции экстракт в количестве 100,0 л сливают в сборник (4) и охлаждают в течение 3–4 часов. Охлажденный экстракт отфильтровывают через нутч-фильтр (5), заправленный фильтром из сукна, в сборник (6).

В экстрактор (3) заливают 100,0 л воды и проводят вторую экстракцию аналогично первой. Второй экстракт в количестве 100,0 л охлаждают, отфильтровывают в сборник (6). Аналогично получают третий экстракт.

Экстракты объединяют и получают 300,0 л (306,5 кг) отфильтрованного водного раствора полисахаридов, который порциями по 20–25 л подают в вакуум-выпарной аппарат (7). Упаривание ведут при температуре 60–70 °C и вакууме 0,04 – 0,08 Мпа (04 – 08 кгс/см²) до получения раствора с содержанием сухого остатка не более 15%.

Упаренный экстракт в количестве 120,0 л подают на распылительную сушилку типа «Anhydro No.2». Сушку ведут при температуре теплоносителя 180–190°C и на выходе из сушилки 85–90°C, при подаче водного раствора со скоростью 5,5 л/ч*м³. Получают 6,1 кг субстанции «Иммунокор экстракт сухой». Выход субстанции «Иммунокор экстракт сухой» составляет – 12,2 % к массе сырья.

По органолептическим и физико-химическим

показателям субстанция «Иммунокор экстракт сухой», полученная по предлагаемой технологии, имеет следующие характеристики:

Описание – порошок красновато-коричневого цвета, гигроскопичный, слегка комкуется, со слабым своеобразным запахом и горьковатым вкусом.

Растворимость – растворим в воде с образованием мутного раствора, практически нерастворим в 95% этиловом спирте и хлороформе.

Подлинность: 1) При добавлении 95% этилового спирта к водному раствору препарата должны появляться хлопьевидные сгустки, выпадающие в осадок при выдерживании в течение 5 мин. (полисахариды). Раствор с осадком фильтруют через стеклянный фильтр ПОР 16, осадок с фильтра переносят в пробирку, прибавляют 5 мл разведенной хлористоводородной кислоты, кипятят несколько минут, прибавляют 10 мл реактива Фелинга и снова кипятят; появляется оранжево-красный осадок (восстанавливающие сахара).

2) Сумма восстанавливающих сахаров – спектр поглощения раствора, приготовленного для определения суммы восстанавливающих сахаров, должна иметь максимум поглощения при длине волны 460 нм.

Потеря в массе при высушивании – не более 10,0%

Тяжелые металлы. Не более 0,01%

Зола общая. Не более 20,0%

Сумма полисахаридов – не менее 15%

Выводы

1. Распылительная сушилка выбрана для сушки водного экстракта н/ч *B. tripartitae*. Оптимальные параметры сушки: температура 180–190 °C (вход)/85–90 °C (выход), скорость подачи 5 л/ч,

концентрация 15 % сухого остатка, давление воздуха 0,2 МПа – обеспечивают влажность 1,9-3,2 %, выход 3,6-3,7 % без прилипания и потемнения субстанции.

2. Разработана технология получения субстанции «Иммунокор экстракт сухой», обладающей иммуностимулирующим действием, из н/ч *B. tripartita*. Данная технология промышленно апробирована на Опытном производстве Института химии растительных веществ и установлено, что выход целевого продукта составляет 12,2% от массы сырья. Внедрение этой технологии позволило рационально использовать н/ч *B. tripartita* и вследствие этого удешевить процесс получения продуктов.

3. По органолептическим и физико-химическим показателям субстанция «Иммунокор экстракт сухой» соответствует нормам: полисахариды ≥ 15 %, влажность ≤ 10 %, зола ≤ 20 %, гигроскопичный порошок красновато-коричневого цвета.

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COMPUTER SCIENCES

INFORMATION SYSTEM FOR TESTING STUDENTS' KNOWLEDGE USING GAMIFICATION ELEMENTS

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Abstract

The article considers the essence of gamification in education, which turned from entertainment into a means of increasing students' motivation to study and attracting them to active participation in the learning process. To increase students' motivation and interest in learning, gamification involves the use of game elements, such as levels, achievements, points, virtual awards, etc. Gamification in education helps students enjoy their achievements. The work describes the author's web-oriented system of testing known students in the subject area "Software engineering and programming". The system uses elements of gamification.

Keywords: gamification in education, software engineering, database, learning content, web-based system for testing, hierarchical model.

Introduction

Gamification is a concept that demonstrates the use of game-based practices in non-game environments. Gamification is used in various areas of human activity (e.g., education, professional activity, leisure).

The essence of gamification in education is to make learning fun and engage students in the learning process [1]. To increase student motivation and interest in learning, gamification involves the use of game elements such as levels, achievements, points, virtual rewards, etc.

Gamification in education is based on positive reinforcement theory, which states that desired behavior can be reinforced by positive consequences. This could include providing virtual rewards for academic success. This approach to learning helps students experience satisfaction from their accomplishments [2].

Gamification in education has several benefits, including:

- increasing student motivation to learn (students are more interested in the process if it resembles a game);

- increasing student engagement in learning;
- ensuring more effective learning (using game elements, tasks and exercises can be developed that will help students more deeply understand and remember the course material);

- increasing the competitiveness and engagement of online courses (courses with gamification elements can be more attractive to students, especially those seeking interactive and fun ways to learn) [3].

Gamification is applicable to various types and forms of learning. For example, gamification can involve the creation of online games or board games that help students learn the course material. In professional training, gamification can be used when learning new technologies or procedures [4].

Gamification can help engage students with different learning styles. For example, students who are more interested in learning when there is competition and play prefer learning that includes elements of gamification [5].

However, gamification is not a universal solution to all learning problems. There are also negative aspects

to using gamification, such as decreased interest in learning if the educational game becomes too difficult or unpleasant for students [6]. Furthermore, gamification requires specific training and effort from instructors and online course developers. Therefore, for gamification to be effective, so-called individualized gamification should be implemented. That is:

- consider the needs and characteristics of each specific group of students;
- consider the needs and characteristics of each student;
- develop reasonable rules and a reward system;
- use tools that provide adequate feedback and analysis of success [7].

Gamification in education is a useful tool for increasing motivation and learning effectiveness. Gamification helps engage students in learning, increase their interest and motivation for learning [8]. It is important to ensure a balance between gamification and traditional teaching methods. In this case, it is necessary to take into account the needs and characteristics of students, and ensure the competent use of gamification to achieve maximum efficiency and effectiveness of learning [9].

Gamification is increasingly widespread in both offline and online learning. Students earn various badges for completing tasks and are placed on a leaderboard that displays each student's ranking in real time. This approach encourages students to achieve their learning goals and earn more points.

Training and testing students learning programming languages and software development environments have long been integrated into the online world. Numerous platforms offer both training and testing tools. One such platform, **w3schools**, combines training and testing for various programming languages. Each section of educational content is followed by a short assignment, which is assessed for correct completion. When logging into this system, in addition to testing, students are awarded points for completing assignments, and the number of completed assignments is calculated. **w3schools** maintains a balance between the direct provision of educational content (training) and testing. The **SoloLearn** platform allows students to determine their level of knowledge only after completing each topic (or block of topics). Students are awarded badges for achievements in various topics they have successfully mastered, as well as experience points for completing assignments, reflecting their level of knowledge.

Research results

We will describe our own software development – web-based system for testing students' knowledge in the subject area “Software Engineering and Programming”. The system incorporates gamification elements.

Development of the system began with the selection of objects that would serve as sections when creating testing blocks. These blocks were defined by the areas of software development and software engineering. These objects, in particular, included: program code in C-like languages (C, C++, C#); web-oriented code (Ja-

vaScript); web-oriented server-side code (PHP); databases (SQL, MySQL); mobile application development (Java).

For each of these topics, common features were identified across all areas. Testing involves the use of common and specific features. For common features, identical questions were created, defining such domain concepts as:

- code file name extension ();
- function declaration syntax;
- variable declaration syntax;
- declaration of variables of different types;
- syntax for creating urgent variables;
- for loop structure;
- while loop structure;
- function call;
- passing function parameters;
- class creation;
- class constructor syntax;
- access modifiers in classes;
- static class methods;
- calling a static class method;
- declaring a class object;
- class inheritance declaration syntax;
- declaring a dictionary as a data type.

Specific features can be reflected, for example, in question blocks related to databases. For databases, the following question blocks were created: database creation syntax; table creation syntax; primary key declaration syntax with increment; foreign key descriptions; field declaration with automatic increment when adding a record to a table; data types; and table view creation. For programming languages, specific features were reflected in the following question blocks, for example: structure declaration syntax (C, C++, C#); associative array (for JavaScript).

The developed system identified the following:

- software development areas (testing subject areas);
- training content topics;
- question groups (blocks) corresponding to training content topics.

Database was developed for data storage, which will store software development areas, topics, and questions related to topics.

Information about spheres is stored in a table containing the following information: the sphere code (which is independent of users, as it is the primary key) and the sphere name.

Information about topics is stored in a table containing: a unique topic code, the sphere code to which the topic belongs, the topic name, and its type. The question table stores data about each specific question. It contains: the question code, the code of the topic to which the question is associated, and the question name, the answer.

All of these tables can be represented as hierarchical model, where the top level reflects areas, the second level reflects topics, and the bottom level reflects questions on a specific topic within the subject area.

To store user testing results, the following table was created:

- student code, login, and password;

- student assessment results table, containing:
 - testing code;
 - student code;
 - code of the area in which the testing was conducted;
 - number of points;
 - testing time.

The developed web-based system provides access to testing knowledge of programming writing. The user first registers/logs in the system, after which they can begin testing in one of the five areas implemented in the system. Questions are presented to the student one at a time for the corresponding area.

After receiving answers (from students) to all questions, the system calculates points (according to the number of correct answers per topic) and determines the student's rating for that topic. All this data is entered into the database along with the student's testing time.

The system is based on hierarchical model, in which each area of the "Software Engineering and Programming" subject area has multiple paths that link to topics within these areas, which are their topics. Each topic has multiple outputs that link to the corresponding test questions. Using hierarchical model allows the system to be scalable to any task, adapting areas, topics, and questions to specific subject area (with its general and specific characteristics).

The system allows access to adding, editing, and deleting any level of the model, so modifications can be made quickly, allowing for the rapid creation of new task blocks. Each of these areas has its own sublevels, which are expanded by clicking the arrow indicating the downward direction. This will reveal all questions on the topic entered into the system.

The system uses gamification elements. An authorized user can access the test by clicking on the names of the corresponding blocks on the system's main page. At first, it seems like nothing out of the ordinary, but that's until the first assignments corresponding to the chosen subject area are completed.

After studying the section's educational content, the student's progress on the test assignments is displayed on the system's main page. This progress reflects (as percentage) the following:

$$\begin{aligned}
 &= \frac{\sum_{i=1}^{n_j} v_i}{\sum_{i=1}^{n_j} mv_i} \\
 &= \frac{\sum_{i=1}^{n_j} v_i}{\sum_{i=1}^{n_j} mv_i}
 \end{aligned}$$

where Pr_j is the student's progress in the j -th section of the course (an indicator of the student's mastery of the educational content of the j -th section of the subject area (course));

j is the course section number, $j = 1, \dots, k$, k is the number of sections in the course;

v_i is the number of points received by the student for completing the i -th assignment ($i = 1, \dots, n_j$) of the j -th section of the course;

n_j is the number of assignments provided by the author to test the student's mastery of the educational content of the j -th section of the course;

$\sum_{i=1}^{n_j} v_i$ – the sum of the points received by the student for completing all n_j assignments in the j -th section of the course;

mv_i – the maximum number of points the student could have received for correctly completing the i -th assignment ($i = 1, \dots, n_j$) in the j -th section of the course;

(mv_i is assigned by the test author for this i -th assignment in the j -th section of the course)

$\sum_{i=1}^{n_j} mv_i$ – the sum of the maximum number of points the student could have received for correctly completing all n_j assignments for the j -th section of the course.

After calculating the Pr_j indicator, the system displays the following indicators to the student:

- the number of points earned by the student (based on the maximum possible number for this section (or block of the section));
- the percentage of correct answers provided by the student;
- the time it took to complete the test; the more tasks completed, the greater the overall progress.

The system will also provide other messages to the student. Upon achieving some success in completing the tests, the student will begin to receive other messages:

- in addition to messages reflecting the student's overall progress, a percentage of how successfully the student completed the test (compared to other students) is also displayed;
- the average test completion time and the student's actual test completion time (displayed in a special color chart: green if the student completes the test faster, red if the student completes the tasks more slowly), with a notification to the student about how quickly or slowly they completed the test.

Gamification is manifested here in the special display of the student's progress and their speed of completing the test tasks. Other elements that gamify the learning (testing) process are used and are displayed on the test task page. The task page displays messages such as the name of the field, the name of the topic, and the current question of the test. Gamification elements are presented here in the form of:

- clock displaying the time allotted for testing;
- notification of the number of tasks already completed.

In addition, new gamification elements are introduced when answering test questions, encouraging students to complete tasks more quickly and accurately. These elements include, in particular, displaying the level of correctness of the corresponding fields of the test tasks and messages to the student, whose test score depends on the correct completion of individual tasks.

If the student answers correctly, they are shown an encouraging message, which can vary (as it is selected from the corresponding table in the system database, which stores phrases that are semantically synonymous). A randomly selected synonymous phrase from this table is presented to the student.

If the student answers the test questions incorrectly or partially correctly, they are presented with a

different message, which will have the following meaning: "Answer incorrect"/"Answer partially correct." Messages will also be selected from a table of synonym messages (synonyms are selected based on semantics).

Fig. 1 shows the window for the first subject area (course), which displays all the topics for which the student will be provided test questions.

Figure 1. Window displaying test topics for the first subject area.

Each topic has its own subtopics. The testing system uses gamification elements, which are applied at different stages of testing (answering test questions). An authorized user can access testing by selecting the corresponding question sets on the system's main page.

After studying the educational content of a section and answering the test questions for that section, the student receives the following metrics on the system's main page:

- progress Pr_j (j is the course section number, $j = 1, \dots, k$, k is the number of sections in the course) for completing the corresponding test tasks for the j -th section;

- number of points scored (out of the possible points for this question set);
- percentage of correct answers; time required to complete the test;
- average time to complete the test (answering test questions for this section);
- place in the ranking list of all students taking the test in this section.

The more tasks a student completes correctly, the greater their overall progress. The assignment page (Fig. 2) displays a block displaying the field name, topic name, and current test question.

Figure 2. Test page window for the subject area "Software Engineering"

Using gamification elements, the student is shown:

- test time (student, average, best);
- number of tasks already completed;
- motivational messages to help complete tasks faster and more accurately;
- graphic (colored) display of the level of accuracy in completing the relevant test fields.

The purpose of the developed software product is to test the knowledge of students studying programming. Using gamification in this learning process creates a desire in the student to earn more points, achieve positive results, complete them in less time, and receive positive feedback (positive messages) from the system.

Initially, the student doesn't feel driven to achieve the best results, but as they complete each set of questions, their progress steadily increases, motivating them to achieve the highest reward (e.g., all correct answers, 100% completion rate, the highest score, and the fastest time among other students). To achieve all these rewards, the student must practice, for example, memorizing which answers were correct to a specific question to achieve the best result in the shortest time.

To begin working in the system, students must register or log in. To do this, click the button "Login" or the section "Log in to view progress" and proceed to the registration/login page. Here, students must enter their login information to register or log in. They must enter their username and password in the appropriate fields and click one of the two buttons on this page. When clicking the button "Register", the student's information will be checked to ensure it is correct and that they are not already registered in the system. If an error occurs during registration, the student will receive a response message. If the student clicks the button "Authorize", the system will check whether they are registered in the system.

After registration/authorization, the student is automatically redirected to the main page of the system, where their name and current progress will be displayed. Under each topic block, it will be indicated that the student has not yet taken the test for that topic/section.

The student can now take the test. To begin testing, the student clicks the image (title) of one of the question blocks in the corresponding subject area "Software Engineering and Programming." After this, the student will automatically be redirected to a page displaying the actual test questions. For ease of use and to make the interface easier to understand, this page also displays the following elements:

- time elapsed since the start of the test (in **minutes: seconds** format);
- name of the testing area;
- current question number and total number of questions;
- question category (displayed on the main page under each area);
- name (wording) of the question to be answered;
- answer entry field (it is partially filled in, and only the missing sections need to be filled in);
- button to confirm the question answer.

The answer entry field consists of fixed text that the student can edit and a field for entering part of the answer. Each answer field contains only one word (one code element). For the question "A function that returns an integer is called main and has no parameters," the result is **int main() {}**. There are four elements, but the input field already has parentheses at the end, so the three elements are split between the three fields, yielding the result (Fig. 3).

The screenshot shows a web interface for a test. At the top, there's a header with 'Тестування ІПЗ' on the left, 'Делант' in the center, and 'Вихід' on the right. Below the header, there's a section with 'Час тесту: 00:13' on the left, 'Код на С подібних мовах (C++, C#)' in the center, and 'Питання №3/22' on the right. The main content area has a title 'Категорія: Синтаксис оголошення функції' and a question 'Питання: Як оголошується функція, яка повертає ціле число, має назву main та не має параметрів'. Below the question, there are four input fields containing 'int', 'main', '()', and '{}'. At the bottom, there is a 'Підтвердити' (Confirm) button.

Figure 3. Example of filling in answer fields

Thus, the answer resembles program code, which is written separately in each input field. To confirm the answer, the student clicks the "Confirm" button, after which they are presented with the test results for the current question.

If the student confirms their answer, the system colors the correct blocks of code green and the incorrect

blocks red. The error in Fig. 4 was intentionally created to demonstrate this coloring. Thus, the student answers the test questions (tasks) and receives their points. After answering all the questions, the student receives their test result (in points) and the test time.

The screenshot shows the same web interface as Figure 3, but after the answer has been confirmed. The input fields now have background colors: 'int' is green, 'maain' is red, '()' is green, and '{}' is green. The 'Підтвердити' button has been replaced by a 'Наступне питання' (Next question) button.

Figure 4. Window after the student confirms their answer

After completing the test, the student can: return to the main page by clicking the "Continue" button to continue testing (with a different set of questions); complete the testing process, receive the results, and log out. When returning to the previous page, the student sees several new sets of questions, gamification elements, etc. (for example, the pre-test result).

The student also sees a display of their entire test results for the entire subject area. The student can see all their statistics and compare them with those of other students (Fig. 5). The first display shows the overall progress, where 100% indicates the student's answers were completely correct in all tests.

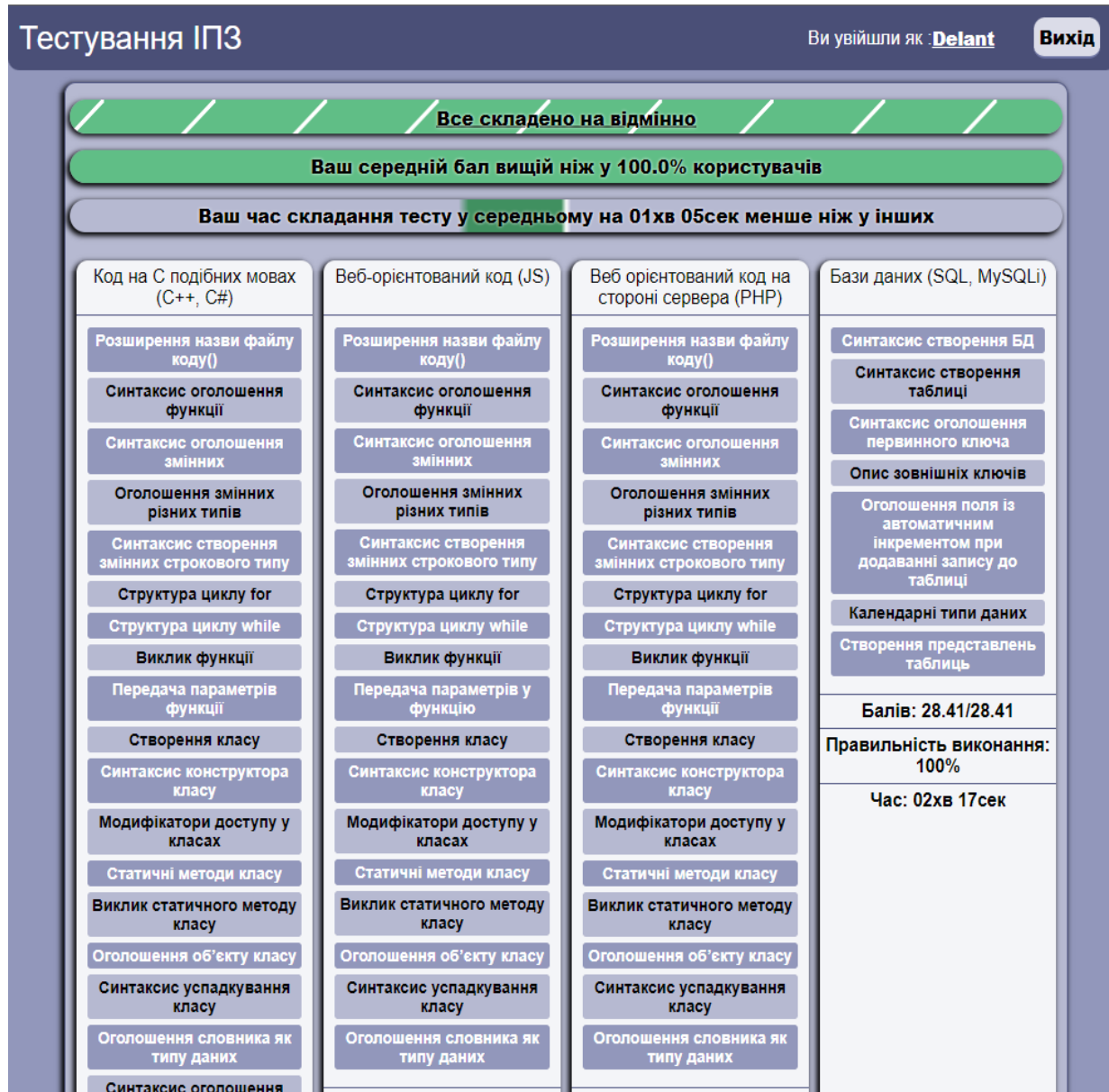


Figure 5. Window with the final test results (statistics) for student receiving only "excellent" grades

Conclusions

This paper analyzes existing approaches to developing testing systems with gamification elements. A system for testing student knowledge in the subject area of "Software Engineering and Programming" was developed, utilizing gamification elements. The developed knowledge testing system will contribute to increased student motivation and improve the overall effectiveness of the educational process (specifically, testing).

The system utilizes hierarchical model of the main components of a subject area (course), where each area of software development has multiple paths that link to topics subordinate to these areas and are their constituent components. Each topic has multiple outputs leading to test questions (question blocks).

The hierarchical model allows the system to be scalable to any assignment, adapting areas, topics, and questions to a specific section (topic or topic block).

The developed system will help students with varying levels of knowledge and skills receive a personalized approach to learning, improving their understanding and retention of the material.

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ECONOMY

SUPPLY CHAIN RESILIENCE ANALYSIS: THE IMPACT OF SYSTEM DYNAMICS

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Abstract

The article analyses the conceptual and practical foundations of supply chain resilience with a focus on system dynamics. Supply chain resilience is defined as the ability of networks to anticipate, absorb, and recover from disruptions while sustaining functional performance. The study formalises resilience through two key parameters: Time-to-Recovery (TTR) and Time-to-Survive (TTS). Using a system of differential equations to represent inventory flows, demand, and supply under disruption, the ratio of TTR to TTS is proposed as a central indicator of system stability.

The research combines theoretical modelling with case-based validation. The literature review traces the evolution of resilience from early frameworks to contemporary approaches addressing ripple effects and pandemic-induced crises. Case studies of Cisco, Toyota, Pfizer, and Amazon illustrate how resilience strategies—such as multi-sourcing, buffer stocks, digital visibility, and collaborative coordination—shape recovery dynamics and operational outcomes.

The results confirm that resilience is achieved through the integration of structural measures (redundancy, geographic diversification, contingency inventories) and dynamic enablers (digital twins, predictive analytics, and adaptive control mechanisms). Importantly, resilience is shown to function not only as a risk mitigation strategy but also as a source of competitive advantage, enabling firms to preserve continuity, safeguard revenues, and capture opportunities during global disruptions.

This study contributes to the development of a unified framework linking system dynamics modelling with empirical evidence. The findings emphasise the decisive role of diversification, digitalisation, and dynamism in designing adaptive and sustainable supply chains capable of withstanding systemic shocks.

Keywords: supply chain, disruption recovery, robustness, flexibility, recovery capability, contingency planning, collaboration, risk management, sustainability, COVID-19, AI and digital twins, redundancy.

1. Introduction

Measuring resilience is challenging, but several metrics have gained acceptance as proxies. A primary metric is **Time to Recovery (TTR)** – the time it takes for a supply chain node or facility to restore full functionality after a disruption. Complementing this is **Time to Survive (TTS)** – how long the supply chain can meet demand during a disruption before running out of stock. Together, TTR and TTS help identify weak links: if TTR for a supplier is greater than the TTS (the buffer time) of the system, the firm will not be able to avoid a supply interruption. These metrics were popularised by practitioners like Simchi-Levi {8} at MIT, and companies have used them to prioritise risk mitigation (e.g. finding backup sources for parts with unacceptably long TTR).

Another widely cited KPI is **Mean Time Between Failures (MTBF)** vs **Mean Time to Recover (MTTR)** – a borrowed concept from engineering reliability to gauge how often disruptions occur and how quickly they are resolved on average. Beyond time-based metrics, firms monitor **performance during disruptions** via KPIs such as **on-time-in-full delivery rate (OTIF)** and **customer service level** under stress. A resilient supply chain will see smaller drops in OTIF when disruptions hit. Inventory-related metrics are also telling: **inventory days of supply** (how many days operations can continue with inventory on hand) indicates buffer capacity, and **cash-to-cash cycle time** (how quickly inventory investment is recovered) reflects flexibility and

efficiency. Companies like *Resilinc* have even developed composite “Resilience scores” for organisations, incorporating factors like supplier redundancy, geographic diversification, and visibility into a single rating. It is worth noting that traditional efficiency metrics (cost, cycle time, asset utilisation) alone do not capture resilience; hence leading organisations are adding **risk-adjusted performance metrics**. For example, the Supply Chain Operations Reference (SCOR) model now includes “*upside supply chain flexibility*” – the ability to **ramp up** output in response to sudden demand or supply changes {9}. In summary, while there is no single measure of resilience, companies benchmark themselves using a **suite of KPIs** that together reflect the agility, redundancy, and robustness of their supply chain. These metrics feed into **dashboard “control towers”** that track risk in real time, enabling proactive mitigation when thresholds (e.g. minimum days of inventory) are tripped.

2. Object and subject of research

In this case, the dynamics of changes in the **functional potential** of one cell of the supply system is considered. The goal is to examine the impact of disruptions on *supply chain behaviour* based on an appropriate dynamic model. The main objectives are:

- **To formalise the concept of resilience** in terms of the parameters TTR (Time-to-Recovery) and TTS (Time-to-Survive);

- **To explore the applicability of a system of differential equations** describing the changes over time

of inventories, demand, and supply volumes to analyse the resilient properties of supply chains;

- **To consider evaluating the stability of supply chains** using eigenvalue analysis of the matrix of the corresponding system of differential equations;

- **To assess the impact of various strategies** (multi-sourcing, buffers, digital visibility) on recovery speed.

3. Research objective

To deepen understanding of supply chain resilience, we will explore three following questions and methodologies to investigate them:

1. **How do sourcing strategies (e.g. single vs. multi-sourcing) affect a supply chain's recovery time after disruptions?** This question examines the link between network design and resilience, such as whether having multiple suppliers for a critical component leads to faster recovery from a supplier failure. *Methodology:* A **quantitative study** could be conducted, using simulation modelling or analytical modelling to compare disruption outcomes under different sourcing configurations. For example, one could simulate a supply network and measure **Time-to-Recovery (TTR)** for single-sourced vs multi-sourced scenarios. Additionally, **empirical data analysis** might be used: collecting data from firms that experienced disruptions and statistically assessing if those with dual sourcing recovered more quickly on average. Such a study might also involve optimisation models (to quantify trade-offs in cost vs resilience) or event analysis of case incidents.

2. **What is the impact of digital technologies (like supply chain control towers, AI-based forecasting, and digital twins) on improving supply chain resilience?** This question explores the role of modern tech in anticipating and mitigating disruptions. *Methodology:* A **comparative case study** approach or **qualitative field research** is suitable. Researchers could conduct **in-depth interviews** with supply chain executives at companies that have implemented advanced visibility and analytics tools. By performing a **cross-case analysis**, one can identify patterns in how technology adoption changed the companies' disruption response (e.g. faster detection of problems, better coordination, reduced downtime). In addition, a before-and-after **benchmark analysis** within a single organisation (evaluating KPI improvements after implementing a digital twin or AI risk system) could yield quantitative evidence. This mixed-method approach would illuminate both the quantitative benefits and organisational enablers of tech-driven resilience.

3. **How can supply chain resilience be effectively measured and what key performance indicators (KPIs) best predict resilient outcomes?** Despite consensus that resilience is important, there is less agreement on how to quantify it. This question seeks to develop or evaluate **metrics for resilience**. *Methodology:* A **conceptual and empirical study** could be done in two phases. First, perform a literature review and Delphi study with experts to identify candidate metrics (e.g. *Mean Time to Recovery*, *Time-to-Survive*, % of orders fulfilled on time during a crisis, etc.). Then, conduct a **survey** of companies to see which metrics they

track and use **statistical analysis** to correlate those metrics with performance during actual disruptions. For example, one might test if companies that monitor and improve their *TTR* and *OTIF* (*On-Time-In-Full*) delivery show higher service continuity when disruptions occur. The outcome would be a proposed **resilience measurement framework** and validation of which KPIs are most indicative of a resilient supply chain.

4. Literature

In the past decade, a rich body of literature on supply chain resilience has emerged. Academically, several *landmark studies* have shaped the discourse. Early foundational work by Ponomarov and Holcomb (2009) defined supply chain resilience and its managerial implications, while Christopher and Peck (2004) introduced resilience in the context of supply chain risk management (emphasising agility and collaboration). In the 2010s, multiple **systematic literature reviews** took stock of progress: for example, Hohenstein et al. (2015) and Tukamuhabwa et al. (2015) reviewed dozens of papers to consolidate resilience strategies and capabilities. These reviews highlighted common resilience enhancers (flexibility, redundancy, visibility, velocity, etc.) and identified research gaps – such as the need to study **trade-offs** (resilience vs cost) and to explore resilience in different contexts (developing economies, service supply chains). Scholars have also developed conceptual frameworks and models. Pettit, Fiksel & Croxton (2010) proposed a resilience framework balancing “vulnerabilities” and “capabilities,” essentially assessing where firms are fragile and how investing in capabilities (like capacity buffers or adaptability) can offset those vulnerabilities. More recently, Ivanov and Dolgui (2020) advanced the understanding of disruption propagation (the “**ripple effect**”) – showing how local disturbances can cascade through globally connected chains, and advocating for resilient design and real-time reconfiguration to contain these ripple effects. The COVID-19 crisis spurred a new wave of academic studies in 2020–2022 analysing pandemic-induced supply chain failures and resilience lessons. For instance, Ivanov and Dolgui (2020) documented how the pandemic revealed unprecedented fragilities and called for new operations research models to handle pandemic-scale disruptions. In parallel, **industry reports and white papers** have provided practical benchmarks. The Business Continuity Institute (BCI) publishes an annual *Supply Chain Resilience Report* that surveys practitioners on disruption incidents and preparedness levels. Consulting firms like **McKinsey** and **Deloitte** have issued reports quantifying the value at risk from supply chain disruptions and recommending strategies (e.g. McKinsey's 2020 analysis suggested up to 40% of one year's earnings are at risk for a severe supply chain shock in certain industries, and advocated regional diversification and inventory buffers). The **World Economic Forum (WEF)** in collaboration with Accenture released “Shared Intelligence for Resilient Supply Systems” (2023), highlighting the need for data-sharing and collective risk visibility across stakeholders to improve resilience. Industry associations (e.g. Association for Supply Chain Management – ASCM) have also produced guides on building

resilience, often emphasising *culture* and *organisation* (governance, leadership support) in addition to technical measures.

5. Research methods

Methodology. A system dynamics approach is applied. Each stage of the supply chain (manufacturer, distributor, consumer) is represented through variables such as inventory, demand level, orders, and deliveries. The model is formalised as a system of first-order differential equations. **The key resilience indicator is considered to be the ratio between TTS and TTR.** In a stable system, $TTS \geq TTR$ (Simchi-Levi et al., 2015).

Furthermore, the study examines several empirical cases of supply chain disruptions experienced by leading multinational corporations. A systematic analysis of these cases allows for the identification of a **set of practical instruments for strengthening resilience**, which were implemented to mitigate or prevent supply chain failures under crisis conditions.

Dynamics of changes in the functional potential of the system after a disturbance
(taking into account the transition function)

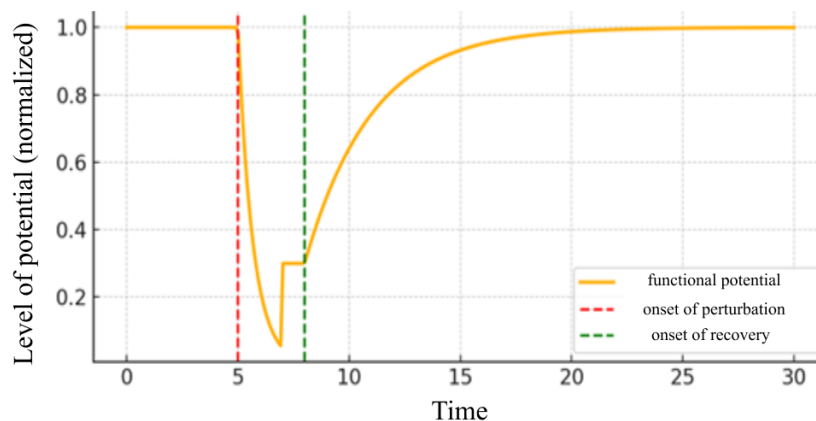


Fig. 1. Graph of the Dynamics of Functional potential

In this graph of functional potential dynamics, one can identify a **breakpoint where the recovery curve changes character: from a jump-like recovery stage to a decelerating phase** with a continually decreasing rate of recovery. Before the breakpoint, the system actively mobilises resources; afterward, recovery continues but at a slower pace.

Clearly, the exponential nature of the recovery process beginning at $t = 8$ is an assumption. However, it allows for evaluation of certain characteristics (or investigation via differential equations or related linear dynamic systems). Two other possible recovery dynamics are:

6. Research results

Modelling the Dynamics of System Functional potential. The graph below shows the dynamics of the system's functional potential in response to an external disturbance (Figure 1). The disruption starts at time $t = 5$ and the decline continues until $t = 7$, with the system's functional potential dropping to 5%.

Given the natural inertia of real systems, we assume that instead of an instant drop, the decline in functional potential occurs gradually and follows an exponential function. Then, at time $t = 7$, a positive external impact stops the decline and leads to recovery of functional potential to 30%. From $t = 7$ to $t = 8$, the system remains at this level. Starting from $t = 8$, the system enters a recovery phase, which lasts until $t \approx 23$.

In this example:

- Time to Recovery (TTR) ≈ 15 time units;
- Time to Survive (TTS) ≥ 15 – assuming buffering, the system maintains functionality.

1. **Two-phase exponential recovery model:** includes two periods of exponential growth — the initial phase (up to the breakpoint) followed by a slower exponential saturation. This results in a system of two linear differential equations with discontinuous temporal characteristics.

2. **Logistic recovery model**, which follows a symmetric S-shaped curve with a clear inflection point.

Figure 2 compares these two alternative recovery models with the single-phase exponential variant. The breakpoint in the two-phase exponential model should correspond to the inflection point in the logistic model, but they are separated in the illustration for clarity.

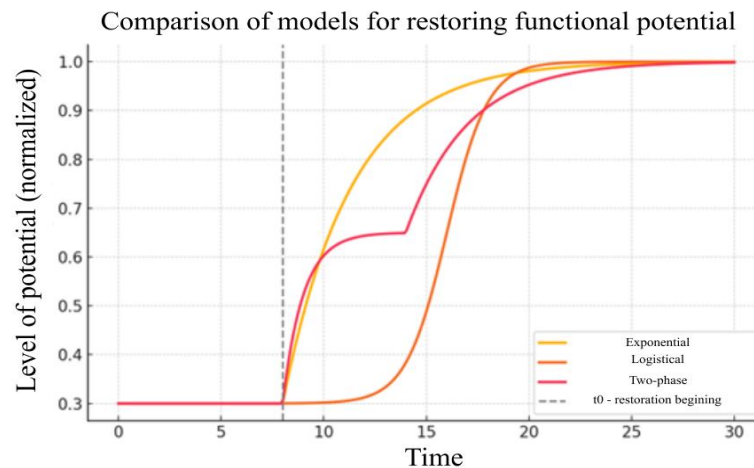


Fig. 2. Graphs of Alternative Recovery Dynamics of Functional potential

The shape of the recovery curve is crucial for evaluating resilience, and the presence of breakpoints or inflection points helps predict exhaustion of adaptive capacity and justify control of recovery speed. Depending on system type, an appropriate model—single-phase exponential, two-phase exponential, or logistic—should be used. This leads to more accurate TTR estimation and supports better decision-making in supply chains.

Interpreting the above, we can state that:

- Implementing strategic buffer stocks significantly reduces TTR;
- Multi-sourcing (alternative supply sources) lowers the risk of failure at individual nodes;
- Digital tools (digital twins, control towers) improve responsiveness through enhanced visibility and forecasting;
- A critical factor is the adaptation coefficient—overly aggressive responses can destabilise the system.

Thus, it can be assumed that dynamic models allow for a formal quantitative assessment of supply chain resilience and can serve as tools for making strategic decisions on buffering, diversification of sources, and ordering policy parameters. This is confirmed by the results of case studies of Cisco, Toyota, Pfizer, and Amazon, where digitalization, buffering, and scenario planning were key components of resilience (SupplyChainDive, 2021).

Cisco Systems (Technology/Cyber)

Cisco Systems, a multinational technology and cybersecurity solutions firm, is known for its sophisticated supply chain risk management program. With over 95% of its product manufacturing outsourced to partners, Cisco recognised early on that **proactive risk management** was essential. Over the last decade, Cisco developed a dedicated **Supply Chain Resiliency team** and invested in advanced risk analytics. A hallmark of Cisco's approach is **scenario planning and preparation**: the company continuously maps critical components and suppliers, identifying points of single-supplier dependency. Suppliers are ranked by risk level (using financial and geographic risk indicators) as "Green/Yellow/Red," and mitigation plans (like qualifying second sources or holding extra stock) are put in place for high-risk ("Red") items. Cisco's resilience

was demonstrated during several crises. For example, when a massive earthquake struck Japan in 2011, Cisco's team **mobilised within 24 hours**. They swiftly assessed which suppliers and factories were affected, and within days launched a 100+ person "war room" to find alternatives and re-route supply lines. This intensive effort over 70 days ensured that Cisco could continue production and meet customer needs despite the devastation in its supply base. Similarly, during Thailand's floods in late 2011, Cisco had **preemptively identified** which suppliers lay in flood-prone regions; when the floods hit, they activated contingency plans and adjusted their logistics flows to minimise impact. Another example of preparedness: in 2008, political protests shut down Bangkok's main airport – Cisco had pre-arranged **truck convoys** to move goods to an alternate airport in Malaysia, thereby avoiding delivery delays. These cases show Cisco's strategy of **real-time visibility and agility** in action. By leveraging a global sensor network (feeds of incident news, supplier status updates) and an established playbook of responses, Cisco consistently maintained supply continuity where competitors faced shortages. Crucially, Cisco's leadership views resilience as a competitive differentiator. As the CEO of Cisco noted, in an increasingly networked world, supply chain risk management is "*top of mind in global organisations as well as a key differentiator for leading value-chain companies.*" {10}.

The results validate this view: Cisco has been able to protect customer service levels and revenue streams during disruptions. For instance, through the 2020 COVID-19 pandemic, Cisco's prior investments meant it had better **visibility into inventory and in-transit shipments**; it quickly re-prioritised production of certain product lines and navigated around lockdown-induced bottlenecks. While no supply chain was unscathed by COVID-19, Cisco's culture of preparedness (e.g. **Business Continuity Plans** with key suppliers) helped it recover faster and meet critical customer needs (such as surging demand for network equipment to support remote work). In financial terms, Cisco avoided the worst of the revenue losses that hit less-prepared competitors, and even gained market share in some segments due to its ability to fulfil orders on time. The Cisco case underlines how **multi-tier mapping**,

risk scoring, rapid response teams, and flexible logistics form a powerful resilience toolkit in the tech sector.

The key implemented tools in this example:

Preparedness & anticipation: Cisco mapped its supply chain, did risk scoring, and ranked suppliers “red/yellow/green”, which shows anticipation and scenario planning.

Flexibility & agility: Mobilized a war room within 24 hours after Japan’s 2011 earthquake — rapid reconfiguration of logistics.

Visibility: Used global sensor networks and risk monitoring dashboards for real-time status.

Collaboration: Worked closely with contract manufacturers to manage risk collectively.

Recovery: Quickly resumed production after major disasters.

Toyota (Automotive)

Toyota Motor Corporation has long been admired for its lean *Toyota Production System*, but in recent years it has also become a study in balancing **efficiency with resilience**. After the 2011 Tōhoku earthquake and tsunami severely disrupted many of Toyota’s part suppliers, the company undertook a comprehensive overhaul of its supply chain risk management. Toyota realised that pure just-in-time with minimal inventory made them vulnerable to catastrophic shocks. In response, over the last decade Toyota implemented several resilience strategies: it **revamped its procurement system** to have alternate sources for ~1,500 crucial parts, mandated that suppliers maintain contingency stocks for key components, and improved communication across its supplier network to detect issues faster. As a result, Toyota entered the late 2010s far better positioned to handle disruptions. These measures were put to the test during the **global semiconductor chip shortage** that began in 2020. Thanks to its earlier resilience planning, Toyota initially weathered the chip crisis better than many competitors. The company had built up a **buffer inventory (around 2–6 months)** for certain semiconductors and had arrangements to switch to alternate semiconductor specifications if one source ran dry. Indeed, Toyota was able to **continue production when others halted** – so much so that in 2021, Toyota overtook GM to become the *top-selling automaker in the U.S.* for the first time ever, an achievement widely attributed to Toyota’s superior supply chain management during the chip shortage. Toyota’s U.S. sales in 2021 *grew* ~10% versus the prior year, while GM’s fell ~13%, reflecting Toyota’s ability to keep dealers stocked when rival brands had empty lots. That said, the scale and duration of the COVID-19 pandemic eventually exposed remaining challenges. Toyota’s contingency plans were designed around handling one or two major disruptions at a time – not dozens simultaneously. By late 2021, as secondary supply issues (e.g. COVID outbreaks in Southeast Asia affecting factories, shipping port backlogs, etc.) accumulated, Toyota too had to temporarily **slash production**. Dealer inventories fell to near zero at one point. Toyota’s management acknowledged that while their resilience was “*better than most*”, the unprecedented

onslaught of the pandemic revealed that further improvements were needed. In response, Toyota is now rethinking its supply chain for the future. Initiatives include making **resilience a core KPI** alongside cost and quality, evolving inventory strategy to hold *45 days or more* of stock for critical items (as a standard practice), and accelerating adoption of digital tools for visibility. For example, Toyota is exploring advanced forecasting and simulation (digital twins) to dynamically adjust inventory and production plans. The company is also localising some supply (producing more components in-house or nearer to factories) to reduce reliance on distant single sources. Overall, Toyota’s case shows a *gradual shift from ultra-lean to lean-but-resilient*. The strategies it employed (multi-sourcing, strategic buffering, quick procurement pivots) yielded tangible benefits – not only mitigating losses, but actually allowing Toyota to capture sales that competitors could not fulfil. Financially, resilience paid off by stabilising Toyota’s revenue and preserving customer loyalty during crisis. The company’s experience also highlights that resilience is a moving target: risks evolve, and even a “best practice” supply chain must continuously adapt its resilience strategies for new threats (be it a pandemic, EV battery material shortages, or other emerging challenges in the auto industry).

In this case we can see as Toyota has implemented lean-but-resilient policy (instead of ultra-lean one) that allows company to extend TTS and ensure a first stage of recovery (Figure 1) using internal resources in the company’s warehouses.

The key implemented tools in this example:

Robustness: Built buffer stocks for chips after 2011, with up to 45 days inventory.

Flexibility: Established multiple suppliers for 1,500 key parts, so they could switch if one failed.

Recovery: During the chip shortage, was able to continue production when others stopped.

Visibility: Strengthened supplier communication to detect problems early.

Collaboration: Engaged suppliers in resilience plans and stockpiling.

Pfizer (Pharmaceutical)

Pfizer, one of the world’s leading pharmaceutical companies, provides a compelling example of supply chain resilience in the context of an extreme surge in demand. In 2020–2021, Pfizer (in partnership with BioNTech) stood up an entirely new supply chain virtually from scratch to produce and distribute its COVID-19 vaccine on a global scale. This presented a unique resilience challenge: rather than recovering from disruption, Pfizer had to **rapidly create a resilient supply chain under crisis conditions**. The company’s success in delivering billions of vaccine doses in record time illustrates resilience through agility, innovation, and collaboration. When the pandemic hit, Pfizer **overhauled its supply chain “on the fly”** to prepare for what was termed “the mother of all demand surges”. Several strategies underpinned this effort: First, Pfizer prioritised **speed over cost** at every step. As Pfizer’s Vice President of operations noted, “*We designed everything based on speed, because every day you delay... could be a death*”. This urgency drove extraordinary

measures to ramp up capacity. Pfizer expanded its manufacturing network to over 20 sites across four continents, including both internal facilities and more than 20 contract manufacturers. It meant **scaling production capabilities by orders of magnitude** – for example, suppliers of specialised lipids (used in mRNA vaccines) who typically provided litres of material for R&D were suddenly asked to supply hundreds of thousands of litres. Pfizer worked closely with these suppliers (providing technical support, funding, and purchasing commitments) to ensure they could meet the new requirements – a demonstration of **deep collaboration with suppliers for resilience**. Second, Pfizer built a new **ultra-cold supply chain** for distribution. The mRNA vaccine needed to be kept at around -70°C , posing a huge logistical challenge since such cold-chain infrastructure was not widely available. In response, Pfizer engineered special thermal shippers with GPS and temperature monitors to ship vaccines globally while maintaining temperature. The company effectively created a “freezer farm” network and strategically located distribution hubs to minimise transit times. This technical resilience (ensuring product integrity through the supply chain) was critical to successful vaccine rollout. Pfizer also leveraged real-time data systems to track every shipment, with contingency plans if any deviation in temperature occurred. The result of these efforts: in less than a year, Pfizer went from zero to producing about **1.9 billion vaccine doses by September 2021**, and had shipped 1.5 billion doses worldwide by that time. Such throughput would normally take many years to achieve; Pfizer managed it in months by strengthening production and logistics “in parallel” with vaccine development. The outcome in terms of resilience is clear – Pfizer’s supply chain was able to **meet a once-in-a-century spike in demand** under extreme conditions. Financially, Pfizer’s vaccine efforts generated tens of billions in revenue, but more importantly, from a public health perspective, the resilient supply chain saved countless lives by getting vaccines to patients in need. Pfizer’s vaccine supply chain story also revealed new facets of resilience: the importance of **public-private coordination** and regulatory flexibility. Pfizer’s executives coordinated with governments worldwide (for procurement guarantees, export/import clearances, etc.) to keep supplies moving. The company had to anticipate and navigate geopolitical risks (such as export restrictions) – which it did by diversifying production across the U.S. and Europe and by engaging diplomatic channels early. In summary, Pfizer demonstrated that resilience is not just about surviving negative events, but also about **surging output under positive pressure** (demand shock) through agility, capacity scaling, and network reliability. Going forward, the “resilience-by-design” approaches used (redundant manufacturing sites, flexible supplier arrangements, digital tracking) are being seen as a blueprint for pharmaceutical supply chains to respond to future health emergencies.

In this case we can see that the company anticipated a positive stress of future demand and had improved supply resilience and readiness to mitigate a first stage decline (Figure 1).

The key implemented tools in this example:

Agility & flexibility: Created an entirely new vaccine supply chain “on the fly” during COVID, scaling up to billions of doses.

Collaboration: Worked intensively with lipid suppliers, regulators, and governments to keep flows moving.

Robustness: Built redundant production across continents.

Visibility: Tracked vaccine shipments in real time with temperature and GPS sensors.

Recovery: Actually “created” capacity under emergency conditions — a form of proactive resilience, not just restoring after a shock.

Amazon (E-commerce)

Amazon, the world’s largest e-commerce retailer, has built its brand on dependable, rapid delivery – a promise it has upheld even amid major disruptions, thanks to a very resilient supply chain and logistics network. Amazon’s supply chain resilience stems from **strategic investments in technology and infrastructure** that allow it to adapt quickly. During the COVID-19 pandemic, Amazon’s capabilities were stress-tested as demand for online orders spiked while global supply lines were snarled. Amazon emerged from the crisis stronger, largely due to its resilience measures. One key to Amazon’s resilience is its extensive **fulfilment and delivery network**. Amazon has hundreds of warehouses (fulfilment centres) across different regions and a last-mile delivery fleet (including its own delivery vans, cargo aircraft, and partnerships with carriers). This **multi-tiered, diversified network** provides flexibility: if one fulfilment centre is hit by a disruption (a COVID outbreak, natural disaster, etc.), orders can be rerouted to other centres with minimal delay. During the pandemic, when certain cities or facilities faced lockdowns, Amazon was able to **shift order volume** to warehouses in other locations and redirect shipments through alternate routes. This rapid reallocation of resources kept goods flowing to customers. For example, Amazon famously prioritised “essential goods” in early 2020 – it dynamically adjusted inventory placement so that vital products (household staples, PPE, etc.) were stocked closer to demand centres, and it temporarily deprioritised non-essentials to ensure core needs were met. This agility in inventory management helped avoid stockouts of important items and maintained customer trust. Another resilience factor is Amazon’s heavy use of **real-time data and AI**. Amazon’s systems forecast demand and detect anomalies using machine learning, enabling proactive response. The company employs **dynamic route optimisation** in transportation. For instance, if there is a sudden transportation disruption (like the 2021 Suez Canal blockage or regional flight cancellations), Amazon’s logistics algorithms can swiftly reroute deliveries (e.g. switch from ocean freight to air for certain shipments, or use alternate ports). During COVID-19, such dynamic adjustments were crucial in navigating bottlenecks – Amazon could divert shipments away from congested hubs and find faster paths, aided by its control over an in-house logistics arm. Crucially, Amazon’s resilience was also supported by **surge capacity** in labor and infrastructure. The company hired over

400,000 additional workers in 2020 to handle the demand and to cover for those who fell ill or had to quarantine. It also expanded its transportation capacity (leasing more cargo planes, chartering ships when needed). Financially, Amazon accepted short-term cost increases (e.g. billions spent on COVID safety measures and capacity increases) as an investment to preserve service continuity. The payoff was evident: while many retailers struggled with empty shelves and delivery delays, Amazon recorded record revenues in 2020–2021, growing ~38% in 2020. It effectively **captured market share** as consumers flocked to the reliable provider. Surveys during the pandemic showed Amazon's customer satisfaction remained high, reinforcing that resilience translated into positive customer experience. In sum, Amazon's case highlights best practices like **end-to-end visibility, flexible fulfillment, diversified logistics, and a culture of rapid innovation**. The company's ability to "scale up" or "re-route on the fly" is a direct result of prior strategic choices – owning more of its logistics network, building excess capacity, and investing in technology like control towers and predictive analytics. For supply chain leaders, Amazon's example underlines that resilience is built in **peace time** (with technology and network design), which then pays dividends in **crisis time**.

The key implemented tools in this example:

Flexibility & agility: Could shift orders to other fulfillment centers or re-prioritize products dynamically.

Visibility: Used AI and machine learning to forecast demand, detect issues, and reroute shipments.

Robustness: Maintained vast fulfillment and delivery networks as shock absorbers.

Collaboration: Cooperated with carriers, temporary workforce, and governments to ensure continuity.

Recovery: Hired 400,000+ extra workers to keep running through COVID.

To summarize, these successful resilience practices can be described as the 3 Ds: **diversification** (of sources and routes), **digitalization** (for transparency and foresight), and **dynamism** (flexibility) in operations. In addition, buffers and cooperation act as force multipliers. These patterns were evident in the case studies and are consistent with broader industry analyses that show resilient companies design their supply chains to accommodate the unexpected and have the means to overcome it.

7. Prospects for further research development

Supply chain resilience has become not only an operational necessity, but also a source of competitive advantage in today's uncertain environment. Companies that have invested in resilience reap tangible benefits: they experience fewer disruptions and shorter periods, maintain customer service when others cannot, and often gain market share and improve their reputation. Studies have quantified the stakes - for example, serious supply chain disruptions can wipe out 10% or more of shareholder value on average, while resilient firms can avoid such losses and even capitalize on competitors' mistakes.

Case studies of **Cisco, Toyota, Pfizer, and Amazon** confirm that resilience translates into real results: Cisco protected its revenues and customers during multiple crises, Toyota turned a chip shortage into a chance

to outsell competitors, Pfizer delivered life-saving vaccines at an unprecedented rate, and Amazon strengthened customer confidence during a global lockdown. In each case, resilience strategies resulted in a more robust and adaptive supply chain that became a strategic asset

8. Conclusion and discussions

Supply chain resilience has become not only an operational necessity, but also a source of competitive advantage in today's uncertain environment. Companies that have invested in resilience reap tangible benefits: they experience fewer disruptions and shorter periods, maintain customer service when others cannot, and often gain market share and improve their reputation. Studies have quantified the stakes - for example, serious supply chain disruptions can wipe out 10% or more of shareholder value on average, while resilient firms can avoid such losses and even capitalize on competitors' mistakes.

Case studies of Cisco, Toyota, Pfizer, and Amazon confirm that resilience translates into real results: Cisco protected its revenues and customers during multiple crises, Toyota turned a chip shortage into a chance to outsell competitors, Pfizer delivered life-saving vaccines at an unprecedented rate, and Amazon strengthened customer confidence during a global lockdown. In each case, resilience strategies resulted in a more robust and adaptive supply chain that became a strategic asset.

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THE IMPACT OF THE WAR IN UKRAINE ON GLOBAL GEOECONOMIC EQUILIBRIUM

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Abstract

The full-scale war waged by Russia against Ukraine has become a catalyst for a profound restructuring of the global geoeconomic system. It has revealed the vulnerability of the world economy to political and military shocks, accelerated the fragmentation of international value chains, and reshaped the structure of global energy flows. The article analyzes the transformation of global equilibrium among the leading geoeconomic centers the United States, the European Union, China, and the countries of the Global South as a result of the war in Ukraine.

Particular attention is given to the role of sanctions policy, the reorientation of energy markets, and the reconfiguration of trade routes and financial flows. It is argued that the war has triggered the emergence of a new multipolar configuration of economic interaction, in which security and technological factors are gaining increasing importance. The study identifies the impact of the conflict on the economic resilience of the EU, China's geoeconomic expansion, and the growing role of military-industrial complexes and the digital economy in shaping global power structures. The conclusion emphasizes that the war in Ukraine has become not only a regional tragedy but also a point of no return for the global economic order, ushering in an era of the "security economy," where political decisions increasingly determine economic development trajectories.

Keywords: geoeconomics, international economic relations, war in Ukraine, global equilibrium, sanctions policy, energy markets, economic security, multipolarity.

Introduction. The war in Ukraine has become an event that has fundamentally altered the logic of the global economic system. For the first time since the Second World War, a military conflict in the heart of Europe has exerted such a far-reaching impact on international financial markets, energy security, trade, investment flows, and institutional relations among the world's major centers of power. Russia's geopolitical aggression has triggered a systemic crisis of globalization, manifested in the fragmentation of global markets, the strengthening of protectionism, and the formation of new blocs of economic interaction.

The relevance of this study lies in the fact that the war in Ukraine has not only deepened the divide between the democratic and authoritarian worlds but has also redefined the economic priorities of states from liberal interdependence toward economic security, resilience, and strategic autonomy. The shift in global balances in energy, finance, and trade indicates a transition to a new model of geoeconomic equilibrium, in which political risks, military expenditures, and technological dominance occupy central positions.

The purpose of the study is to analyze the mechanisms through which the war in Ukraine influences the structure of global geoeconomic equilibrium, to identify the main directions of reconfiguration among the world's economic centers, and to reveal new trends in interactions among leading powers.

The object of the research is the transformation processes of international economic relations under the influence of geopolitical conflicts.

The subject of the research is the structural shifts in the global economy caused by the war in Ukraine and their impact on the formation of a new system of geoeconomic equilibrium.

The scientific novelty of the study lies in the comprehensive analysis of the war as a trigger for global economic shifts occurring simultaneously across financial, energy, technological, and security dimensions. The paper proposes a conceptual vision of the war as a driving factor of the transition from a globalized to a bloc-oriented economy.

Research Methodology. The methodological framework of the study is based on the integration of systemic, geoeconomic, and neo-institutional approaches, which together enable a comprehensive understanding of global economic transformations under the influence of war. The systemic approach made it possible to view international economic relations as an interconnected structure of political, financial, energy, and technological flows that respond to conflict events through mechanisms of adaptation, resistance, or resource redistribution.

The geoeconomic approach was employed to identify changes in the spatial configuration of the world economy particularly in the distribution of energy centers, trade routes, and financial flows. This approach allowed the tracing of a new "map of power" among the United States, the European Union, China, the countries of the Global South, and emerging regional alliances.

The neo-institutional approach was applied to analyze the responses of international economic organizations (IMF, WTO, OECD, and the World Bank) to the consequences of the war and to study the institutional restructuring of global governance. The research methods included:

- 1) Comparative analysis — to contrast macroeconomic indicators and behavioral models of major geoeconomic actors;
- 2) Economic and statistical methods — to analyze changes in international trade, investment flows, energy balance, and GDP dynamics;
- 3) Scenario forecasting — to assess possible trajectories for the post-war development of the world economy;
- 4) Content analysis — of analytical reports by the European Commission, the World Bank, OECD, SIPRI, IMF *World Economic Outlook*, and *Global Risks Report*.

The theoretical basis of the study draws upon the works of J. Stiglitz, D. Rodrik, H. Minsky, R. Haass, and G. Friedman, as well as contemporary Ukrainian scholars such as V. Heiets, V. Sydenko, O. Mozghovyi, and A. Hrytsenko, whose research addresses economic security and the geoeconomic resilience of states.

The obtained results are grounded in the principles of objectivity, interdisciplinarity, and empirical verification, allowing the war to be considered not only as a military-political event but also as a structural economic phenomenon of global significance.

Literature Review. The impact of the war in Ukraine on global economic equilibrium has attracted significant scholarly attention within the fields of international economic relations, geoeconomics, and security studies. In the works of J. Stiglitz [1] and D. Rodrik [2], it is emphasized that modern globalization remains highly vulnerable to political crises, while geopolitical conflicts have the potential to fundamentally alter the logic of economic interdependence. According to analytical reports by the International Monetary Fund and the World Bank [3,4], the full-scale war in Ukraine has led to the most severe energy and food shock in decades, undermining macroeconomic stability across much of the world.

R. Haass [5] interprets the conflict as a manifestation of the process of *de-globalization*, characterized by rising regionalism, protectionism, and political intervention in market mechanisms. Similarly, G. Friedman [6] highlights the shift of economic power centers toward states possessing critical resources — energy, food, and dual-use technologies.

Among Ukrainian scholars, a significant contribution to the analysis of the war's global economic consequences has been made by V. Heiets [7], V. Sydenko [8], O. Mozghovyi [9], and A. Hrytsenko [10]. They argue that the war in Ukraine has become a trigger for a new wave of geoeconomic redistribution, in which energy autonomy, financial resilience, and technological security come to the forefront.

Analytical publications by the European Commission [11], the OECD [12], and SIPRI [13] further confirm that the sanctions policy imposed against Russia

and its allies has restructured international trade, accelerated the diversification of energy supplies, and intensified global competition for export markets. At the same time, China and the countries of the Global South are using this situation to expand their influence, forming alternative financial and logistical alliances.

Thus, the contemporary academic discourse points to the emergence of a new paradigm of geoeconomic equilibrium, where political risks, military conflicts, and security factors are becoming key determinants of international economic relations. Nevertheless, despite the growing body of literature, there remains a need for a comprehensive study of the *Ukrainian factor* as a structural element of these global transformations which constitutes the central aim of this research.

Research. The war in Ukraine has profoundly altered the logic of global economic development, giving rise to a new model of geoeconomic interaction in which economic processes are increasingly intertwined with political, military, and security determinants. Whereas in previous decades the global economic system evolved under the paradigm of liberal interdependence, since 2022 it has been dominated by the principle of strategic caution, fragmentation, and the “economy of power.” The war has acted as a catalyst that transformed competition among the world's leading powers from trade rivalry into a struggle for economic survival, technological autonomy, and security resilience.

According to estimates by the *IMF World Economic Outlook (2025)*, *OECD Economic Outlook (2024)*, and *World Bank Global Economic Prospects (2024)*, the world economy between 2021 and 2024 has exhibited asymmetric growth. The United States continues to maintain macroeconomic stability due to a flexible labor market, diversified energy resources, and technological leadership. China, after a slowdown caused by the pandemic, is regaining momentum but faces mounting internal debt and constraints in real estate investment. The European Union, by contrast, is experiencing its deepest economic downturn in decades, driven by an energy crisis and the restructuring of supply chains. Meanwhile, the countries of the Global South have emerged as new “growth players,” benefiting from the relocation of capital, investment, and production capacities away from geopolitically unstable regions.

The war has also redefined the spatial configuration of global trade and energy flows. Europe's rapid reduction in dependence on Russian oil and gas from 41 % to less than 8 % by 2023 has reshaped global energy logistics, redirecting trade routes toward North America, the Middle East, and Africa. China and India, on the other hand, have absorbed a significant share of Russian energy exports, forming an alternative eastern energy corridor. This “energy bifurcation” marks the division of the global market into Western green transition economies and Eastern resource-based alliances.

At the financial level, the conflict has accelerated the diversification of international payment systems and the gradual erosion of the U.S. dollar's dominance. The share of the dollar in global settlements has decreased from 59 % in 2021 to 56 % in 2024, while the

euro has modestly increased its position, and the Chinese yuan has more than doubled its share — from 2.9 % to 5.7 %. This trend reflects the beginning of a multipolar currency order, where financial sovereignty and sanctions resilience are becoming crucial elements of national security.

The defense sector has emerged as a new driver of global industrial growth. In 2023–2024, global military expenditures reached their historical maximum — over USD 2.4 trillion (SIPRI, 2024), with the United States, China, and the EU collectively accounting for nearly three-quarters of total defense spending. At the same time, investment in dual-use technologies — cybersecurity, artificial intelligence, drones, and quantum computing — has intensified, highlighting the convergence of economic competitiveness and military capability.

For Ukraine, the war has paradoxically opened both the greatest challenges and unique opportunities. Despite massive destruction and GDP contraction of over 30 % in 2022, the country has become a strategic hub for reconstruction, logistics, and defense innovation. The EU's *Ukraine Facility 2024–2027* and IMF's Extended Fund Facility programs form the institutional basis for integrating Ukraine into European production and financial networks, thereby transforming it into a core element of the emerging European security economy.

Overall, the empirical evidence supports the conclusion that the war in Ukraine has transformed globalization into fragmented geoeconomization — a system where regional alliances, technological autonomy, and security imperatives now determine the trajectory of global economic equilibrium.

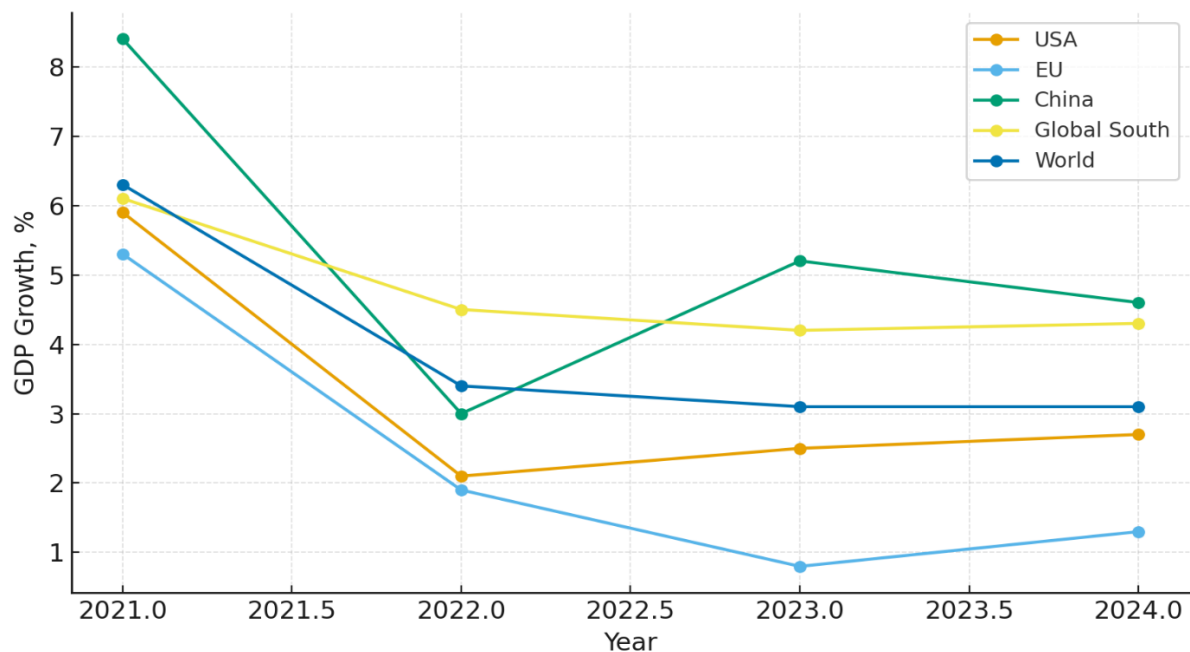


Fig. 1. GDP Growth Dynamics, 2021–2024 (% y/y), based on data from IMF, OECD, and World Bank (2025).

From the figure above, it can be observed that global GDP growth rates reveal a clear trend toward the “stratification” of the world economy. The United States has successfully adapted to the new configuration owing to its dominance in high-technology industries, digital services, and a robust military-industrial complex. In contrast, the European Union’s economy has suffered from an energy shortage and the loss of Russian markets, resulting in an industrial downturn in Germany, Italy, and the Czech Republic. China remains the key locomotive of the Global South; however, its growth is slowing due to structural constraints within its domestic market. These processes signal a transition from global economic interdependence to a multipolar system of power centers, in which economic equilibrium is shaped not by shared rules but by political alliances [14].

One of the most evident consequences of the war has been the profound transformation of global energy flows. The European Union, which for decades built its energy architecture on inexpensive Russian gas, has undertaken an unprecedented shift toward alternative suppliers. According to the *International Energy Agency (IEA, 2025)*, EU imports of Russian energy resources declined from 41.2 % in 2021 to 7.9 % in 2023, while the United States, Norway, and Qatar became its main new suppliers. This process has resulted not only in greater energy diversification but also in a reconfiguration of international relations, within which energy has evolved from a purely economic to a strategic category an instrument of influence and security in the new geoeconomic order.

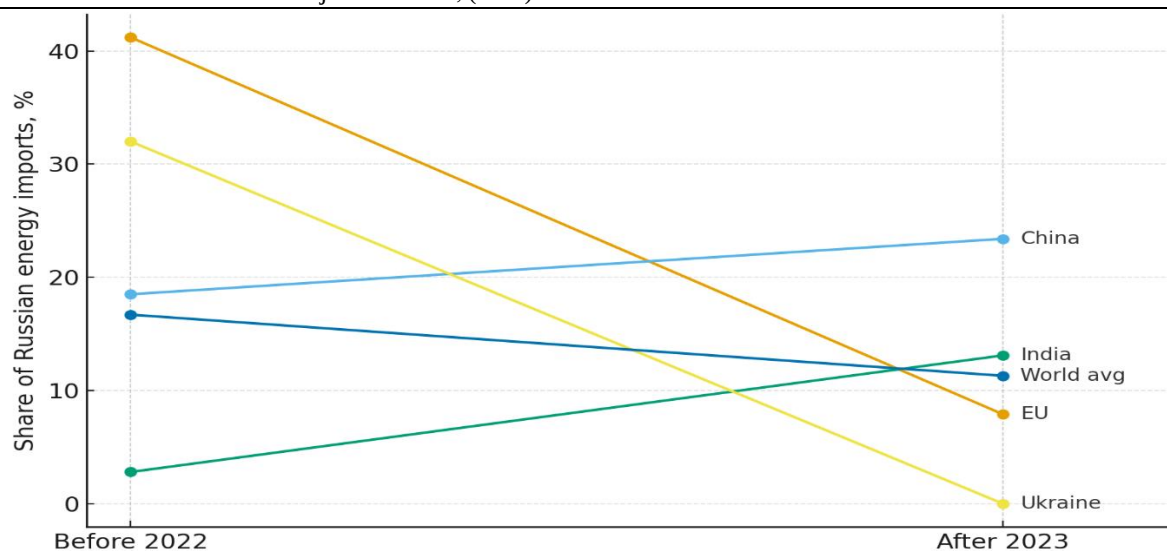


Fig. 2. Energy Reorientation: Decline in Dependence on Russian Energy Resources (based on IEA and Eurostat data, 2024).

As shown in the graph, the European Union has achieved an unprecedented reduction in its energy dependence on Russia within a remarkably short period — an economic equivalent of a “*decolonization process*.” Ukraine, despite the colossal destruction of its energy infrastructure, is gradually integrating into the European energy network, importing electricity from Poland and Slovakia. At the same time, China and India have effectively replaced European demand by increasing their imports of Russian oil and gas, thereby reinforcing the emerging “Moscow–Beijing–Delhi” energy axis.

Consequently, a new energy geopolitics is taking shape: the West is moving toward autonomy and diversification, while the East is heading toward resource consolidation and interdependence.

The large-scale sanctions campaign imposed against Russia and its allies has led not only to the financial isolation of certain states but also to significant shifts in the global currency architecture. According to the IMF COFER (2025) database, the share of the U.S. dollar in international settlements is steadily declining, while the roles of the euro and, particularly, the Chinese yuan are expanding. This trend is not merely a statistical fluctuation but a reflection of deep structural changes within the global financial geoeconomy — signaling the gradual emergence of a multipolar monetary order that mirrors broader transformations in the world’s political and economic balance of power.

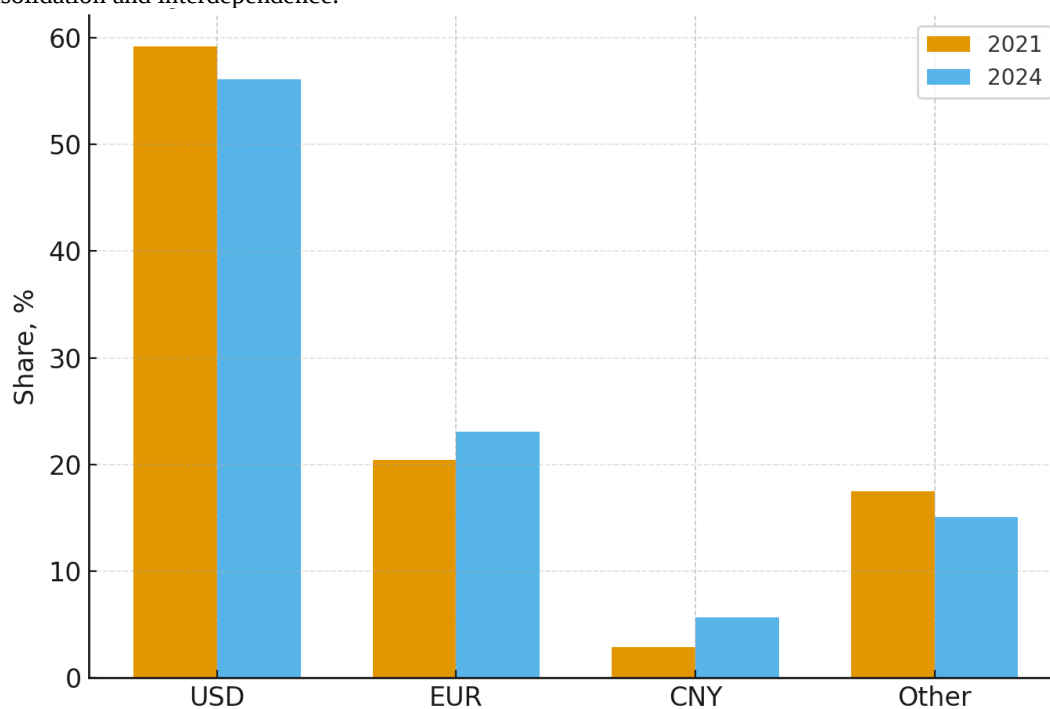


Fig. 3. Currency Structure in International Settlements: 2021 vs 2024 (based on SWIFT and IMF COFER data, 2025).

The gradual currency diversification reflects a tangible shift in global financial power toward the East. The rising share of the Chinese yuan represents a strategic move by Beijing to establish an alternative financial ecosystem ranging from its Cross-Border Interbank Payment System (CIPS) to the digital yuan, which is steadily gaining integration into international settlements. The European Union seeks to strengthen the role of the euro, particularly through *green bond* projects and defense sector financing, while the United States continues to maintain monetary dominance through its institutional influence and control over global payment infrastructures.

The war in Ukraine has become a crucial trigger for rethinking the role of finance in international relations. The global economic architecture once governed by universal rules now increasingly operates as a mosaic of regional currency blocs, where financial policy reflects political alignment and trust-based alliances [15].

Between 2022 and 2025, Ukraine has undergone a complex transformation from the object of external aggression to a subject of international influence. The country is emerging as a *laboratory of new economic models* encompassing digitalization, *green reconstruction*, defense cooperation, and integration into European markets. The Ukraine Facility (2024–2027) program allocates more than €50 billion in investments toward the modernization of energy, transport infrastructure, the defense-industrial complex, and digital transformation. Economically, this marks the gradual formation of a new Eastern European economic arc, combining energy security, industrial synergy, and integration potential within the frameworks of the EU and NATO [16].

The war in Ukraine has become a geoeconomic detonator of global transformations. It has disrupted the old logic of the world economy where profit often prevailed over political values and has inaugurated a new era in which financial, energy, and trade flows are increasingly determined by security, trust, and identity considerations.

The global equilibrium of the 21st century is no longer formed on the basis of economic liberalization but rather on the principles of value selectivity, energy autonomy, and technological sovereignty. Positioned at the epicenter of this new architecture, Ukraine is not merely an arena of confrontation but an active architect of the emerging global economic order.

Conclusions

The conducted research demonstrates that the full-scale war in Ukraine has become a pivotal factor in the systemic transformation of the global economic order. It has not only destabilized traditional models of international interaction but has also initiated the formation of a new type of geoeconomic equilibrium grounded in security, technological, and energy priorities.

First, there has been a clear shift from globalization-based interdependence toward regionalism and polycentricity. The liberal economic model once characterized by the free movement of capital, goods, and technologies is being replaced by network alliances founded on political trust and strategic proximity. New

centers of power have emerged the United States, China, the European Union, India, and the consolidated Global South which compete economically while simultaneously developing ideologically distinct models of growth.

Second, the energy dimension of the war has revealed the deep dependence of the modern economy on political decision-making. Europe's rejection of Russian energy carriers has led to a large-scale reconfiguration of energy flows, a shift toward renewable sources, and the strengthening of transatlantic energy partnerships. Conversely, China and India have deepened their energy ties with Russia, shaping an alternative configuration that reinforces the eastern axis of the global economy.

Third, in the financial sphere, a gradual currency diversification is evident. The declining share of the U.S. dollar in international settlements and the growing weight of the euro and the yuan indicate a transition toward a multipolar financial system. The war in Ukraine has accelerated this process, showing that financial instruments can serve not only as tools of economic exchange but also as weapons of influence and collective pressure.

Fourth, Ukraine is acquiring a strategic status within the emerging system of global security. The country is transforming into a key economic and logistical hub between the EU, NATO, and the Black Sea region. EU and IMF investment programs form the foundation for developing in Ukraine a model of a "resilience economy", combining military-industrial modernization, digitalization, green reconstruction, and integration into European production networks. Based on the findings, several practical policy recommendations for Ukraine's economic strategy can be formulated:

1. Prioritize integration into the European energy space, focusing on the development of green generation, hydrogen energy, and energy efficiency.
2. Develop digital infrastructure and technological hubs to ensure Ukraine's participation in transborder EU innovation clusters.
3. Strengthen financial resilience by attracting strategic investors, expanding export credit guarantees, and developing a wartime recovery capital market.
4. Engage actively in regional security-economic alliances aimed at diversifying logistics and industrial value chains.
5. Promote humanitarian and economic diplomacy that bridges security, reconstruction, and Ukraine's positioning as a connecting state between the West and the Global South.

In summary, the war in Ukraine has revealed that the economy is no longer a neutral sphere it has become an instrument of political struggle, a pillar of national security, and simultaneously a platform for innovative strategies. The new world order taking shape before our eyes will be determined less by globalization and more by the ability of states to adapt rapidly to uncertainty, maintaining a balance between openness and sovereignty.

Ukraine has the potential to become a model of this new era, a country that combines a digital economy, energy independence, and democratic identity

within the evolving system of global security in the 21st century.

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ПОТЕНЦИАЛЪТ НА ОБЩИНСКИТЕ ФЕСТИВАЛИ ЗА РАЗВИТИЕТО НА ТУРИЗМА

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THE POTENTIAL OF MUNICIPAL FESTIVALS FOR TOURISM DEVELOPMENT

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DOI: [10.5281/zenodo.17668217](https://doi.org/10.5281/zenodo.17668217)***Анотация**

Фестивалният туризъм в България е важен инструмент за развитие на културния и туристическия сектор, като особено място заемат общинските инициативи, обединяващи традиции, културни практики и туристически дейности. Картографирането на фестивалите показва по-голяма концентрация на събития в Северна България и доминиране на есенния сезон, което допринася за удължаване на активния туристически период. Ефективната им реализация изисква стратегическо планиране, маркетинг и сътрудничество между местната власт, бизнеса и културните общности. Общинските фестивали могат да се превърнат в устойчиви туристически брандове, които насърчават културното развитие, социалната интеграция и повишават конкурентоспособността на дестинациите.

Abstract

Festival tourism in Bulgaria represents a significant tool for the development of both the cultural and tourism sectors, with municipal initiatives playing a key role by combining traditions, cultural practices, and tourism activities. The mapping of municipal festivals reveals a higher concentration of events in Northern Bulgaria and a predominance of the autumn season, which contributes to the extension of the active tourist period. Effective promotion and management require strategic planning, marketing, and cooperation between local authorities, businesses, and cultural communities. Municipal festivals have the potential to evolve into sustainable tourism brands that foster cultural development, social integration, and enhance the overall competitiveness of destinations.

Ключови думи: фестивален туризъм, общински фестивали, културно наследство, устойчиво развитие, туристически бранд, регионално развитие, социална интеграция.

Keywords: festival tourism, municipal festivals, cultural heritage, sustainable development, tourism branding, regional development, social integration.

Introduction

Festival tourism has been gaining increasing importance in the contemporary tourism industry, emerging as one of the most dynamically developing segments within cultural and event tourism. According to Getz (2008), events and festivals are a powerful tool for stimulating tourist flows, building the image of destinations, and promoting local development. Festivals represent a specific type of anthropogenic tourism resource, whose attractiveness stems from their ability to integrate cultural, social, and economic dimensions.

Festival tourism can be considered both a subtype of event tourism and a form of cultural tourism, depending on the nature and thematic focus of the main event. It may develop as an independent tourism product or as a complementary element to other types of travel. The importance of festival tourism manifests through several key functional aspects. It constitutes a significant economic resource for local communities by generating income and stimulating small and medium-sized enterprises in the regions where such events take place. Festivals also function as a strategic tool for destination marketing and promotion, contributing to the establishment and strengthening of a positive image among domestic and international visitors. Moreover, festival tourism fulfills a cultural-regulatory function, contributing to the preservation and popularisation of

local traditions, customs, and cultural heritage according to the specific character and theme of each event. This form of tourism supports the development of cultural and artistic communities by stimulating creative activity, encouraging the exchange of ideas, and fostering social integration within the local community.

As a niche and alternative form of tourism, festival tourism has the potential to mitigate seasonality in mass tourism by extending the active summer and winter seasons. This makes it particularly valuable for small and medium-sized destinations seeking sustainable mechanisms for development. For this reason, the study of the potential of municipal festivals for tourism development is important from both scientific and practical perspectives, as it provides guidelines for the effective planning, organisation, and marketing of festival events at the local level.

The main objective of this study is to analyse the opportunities and preconditions for the development of festival tourism in Bulgaria through a focus on municipal festivals. The paper outlines the theoretical foundations of festival tourism, maps festivals of municipal significance, and presents a territorial analysis of their distribution across regions and districts. To achieve this goal, regional and municipal tourism development strategies were reviewed, along with data from the Register of Tourist Attractions and Events.

1. The Essence of Festival Tourism

The potential of municipal festivals for tourism development lies in their capacity to attract visitors, encourage intercultural exchange, and create a positive image of the local community. According to Lopes and Hiray (2024), festivals and cultural events “offer unique experiences that attract tourists while shaping the identity and vitality of local communities.” They often become instruments for the construction of local identity and social cohesion. As noted by Jaeger and Mykletun (2013), festivals “influence individual and social identities” and provide “opportunities for collective belonging and place-based identification.”

Owing to their accessibility and thematic diversity, municipal festivals can evolve into sustainable models for stimulating domestic tourism, particularly in smaller settlements with limited resources but rich cultural heritage. Beyond their cultural and social significance, festivals also have a clear economic impact. Shelton's (2017) study on the economic effects of festivals in small towns highlights the dual nature of these events: on one hand, they can stimulate the local economy through increased business activity and tourist arrivals; on the other, they can impose substantial costs, including inflationary pressure, infrastructure congestion, and risks of local population displacement.

Well-organised festival events can develop into annual attractions that maintain a steady tourist flow, thereby diversifying the tourism offer and extending the tourist season. Felsenstein and Fleischer (2003) emphasise that local festivals are increasingly used for tourism promotion and regional economic stimulation, with sustainable development achieved through the integration of economic growth and good governance.

In the long term, municipal festivals can contribute to the strategic positioning of a destination as a cultural hub or a city of the arts, thereby encouraging investments, partnerships, and innovations in the tourism sector. To realise this potential, a synergy must be established between municipal cultural policies and the marketing strategies of tourism and cultural organisations.

2. Festivals in Bulgaria: The Role and Importance of Municipal Festivals

Festivals in Bulgaria represent a diverse range of cultural events that enrich the social and economic life of local communities. The main types of festivals include music, film, culinary, cultural, and art festivals. Depending on their theme, scale, and participants, their significance may be local, national, or international. Festival tourism in Bulgaria has deep historical roots, and in recent years, there has been an increasing interest in its development at the municipal level. Many local authorities recognise the potential of festivals not only as cultural events but also as strategic instruments for regional development and social integration.

According to Petkova (2022), local festivals in Bulgaria, regardless of their thematic orientation, typically combine elements of traditional celebrations with

modern forms of collective participation and interaction. These events often serve a social-constructive function by supporting the processes of forming and reaffirming local identities. Such identities are built upon representations of cultural heritage that are reconstructed and systematised as resources and symbols of importance to the community.

Across numerous Bulgarian municipalities, traditional cultural events are organised that represent short-term but significant social practices, typically concentrated within a single day or a few days. During these festivities, local residents actively participate in performances of traditional dances and songs and prepare traditional foods and beverages. According to Terziyska (2016), despite their cultural and social importance, the organisation and financing of such events rarely follow a systematic or standardised approach. Practices vary considerably between settlements: in some municipalities, the primary funding is provided by the local budget, while in others, resources are secured through private sponsorship; the main organisers also differ – in some cases, the events are coordinated by the local administration, while in others, they are managed by non-governmental organisations or volunteer groups.

This diverse organisational structure reflects both local specificities and resource capacities, as well as the different models of social participation and community engagement in the cultural life of the settlement.

3. Mapping of Municipal Festivals in Bulgaria

The mapping of municipal festivals in Bulgaria represents a systematic approach to identifying, classifying, and analysing cultural events at the local level. This process provides a clear understanding of the spatial distribution of festivals across the country, highlighting areas with a high concentration of events as well as regions with potential for developing new cultural initiatives. The mapping of municipal festivals also serves as an instrument for evaluating their role in preserving cultural heritage and stimulating cultural and artistic communities – a key aspect of sustainable tourism development at local and regional levels.

For the purposes of this study, a thematic map was created to reflect the spatial distribution of municipal festivals in Bulgaria. Data were obtained from the Register of Tourist Attractions at the level of significance “municipal” (<http://rta.tourism.government.bg/TFRegister.aspx>). A total of 43 entries were identified from the register, which were imported and systematised in tabular format. The table was spatially linked to a shapefile containing the administrative boundaries of Bulgarian municipalities (polygon-type data). Following spatial integration, the municipalities hosting festivals were isolated, and the number of festivals per municipality was indicated through a point layer. The resulting map (Fig. 1) visualises the spatial patterns and concentrations of municipal festivals across the country.

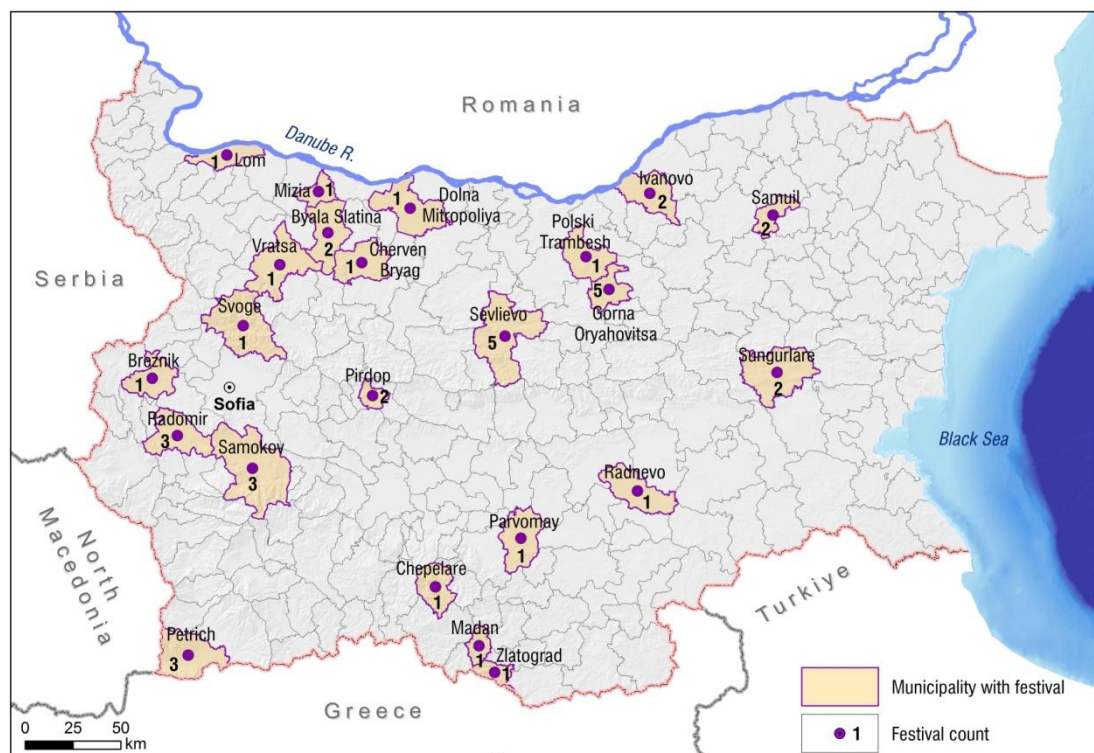


Fig. 1. Municipal-level festivals in Bulgaria

The analysis of the map reveals a higher concentration of festivals in Northern Bulgaria compared to other parts of the country. This tendency can be explained by the fact that the region is relatively less developed in tourism terms, and the organisation of festivals is used as a tool for diversifying and activating the tourism product. A particularly high density of festivals is recorded in the municipalities of Gorna Oryahovitsa

and Sevlievo, which stand out as local cultural centres with well-established festival traditions. Furthermore, an analysis of the temporal distribution of events (Fig. 2) indicates that the largest number of festivals are held during the autumn season. This can be interpreted as a deliberate strategy to extend the tourist season and attract visitors beyond traditional vacation periods.

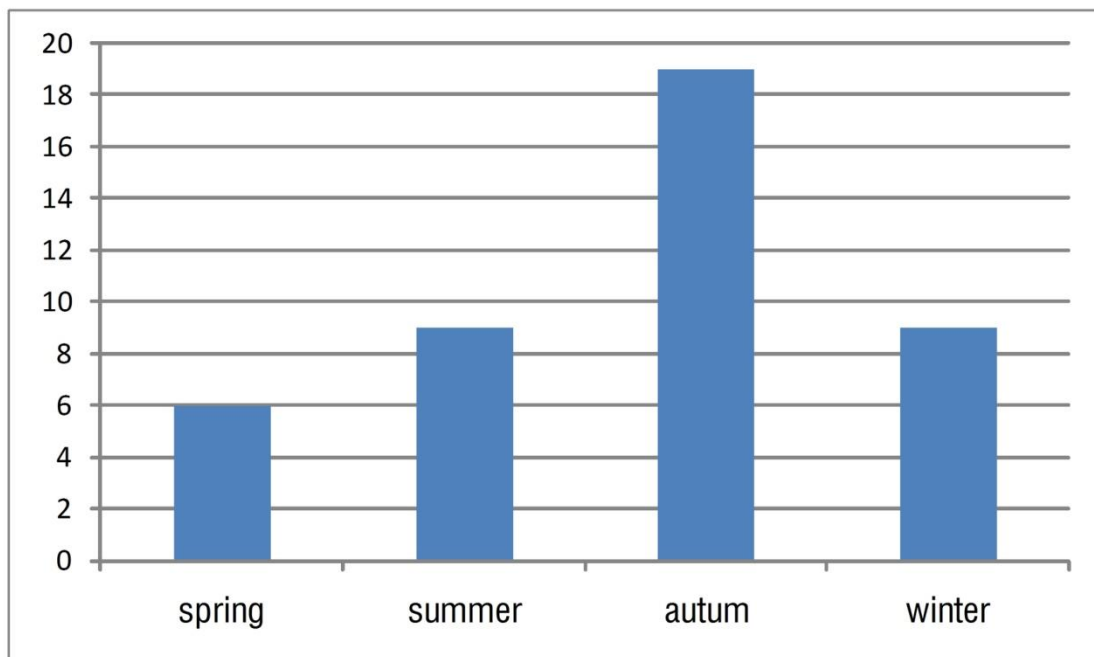


Fig. 2. Seasonal distribution of municipal festivals in Bulgaria

The mapping of municipal festivals provides valuable insights into the spatial structure of cultural

events in Bulgaria and establishes a foundation for future analyses of regional cultural and tourism development.

4. Strategies for Promoting Municipal Festivals

The effective promotion of municipal festivals requires a structured and multidimensional communication strategy that treats the event not only as a cultural phenomenon but also as an integral component of the destination's tourism product. Marketing through new media – including websites, social networks, and digital content – plays a crucial role in expanding the tourism market and actively engaging target audiences.

The creation of a festival identity through a visual brand, thematic content, and interactive formats is considered a key factor in stimulating attendance and building loyalty. Kitterlin-Lynch and Yoo (2014) found that “festivalscape” factors significantly influence visitors' motivation and subsequent loyalty.

The promotional strategy should integrate the concept of a destination brand. According to Ahmed et al. (2025), socio-cultural festivals have the potential to shape the regional image as a tourism brand through two-way communication, content creation, and active participant engagement.

An effective strategy for promoting municipal festivals should be based on partnerships among local administrations, businesses, media, and volunteer groups. It should also involve integrating festival activities into broader tourism routes and thematic packages. This approach not only increases the visibility of the event but also optimises its contribution to the sustainable development of tourism within the destination.

Conclusion

Festival tourism in Bulgaria represents a significant resource for the development of both the cultural and tourism sectors, with particular potential revealed through municipal initiatives that combine cultural values, traditions, and attractive tourism practices. The conducted analyses demonstrate that the effective utilisation of this potential requires strategic planning, marketing positioning, and sustainable management of festivals to ensure their continuity and economic, social, and cultural value.

Municipalities play a crucial role in the organisation, promotion, and integration of such events into the destination's overall tourism offer. When well-structured and purposefully promoted, municipal festivals can establish themselves as local and regional tourism brands that not only attract visitors but also contribute to the preservation of cultural heritage, the strengthening of local identities, and the promotion of social integration.

The development of festival tourism requires coordinated efforts between local authorities, businesses,

and cultural and artistic communities, allowing municipal festivals to realise their full potential as a driver of sustainable cultural and tourism development in Bulgaria.

Acknowledgement

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ELECTRICAL ENGINEERING

DISTRIBUTION OF WAGON FLOWS OF THE PORT TRANSPORT AND TECHNOLOGICAL SYSTEM: DEVELOPMENT OF MODELING

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Abstract

The direction of the research is the efficient use of the rolling stock of operating companies. The research uses methods of mathematical modeling in terms of economic and geographical definition of «areas of influence» involved in the process of transportation of stations. The result of the research is a geometric routing model that characterizes the competitive market for the transportation of empty cars initiated from selected departure stations.

Keywords: wagon flow, port transport system, modeling, areas of influence, higher-order algebraic curves.

The management of empty wagon flows represents a critical challenge in transport logistics, particularly under the constraints of evolving economic geographies and stable freight volumes. Efficiently reallocating these empty wagons not only optimizes resources but also significantly enhances the sustainability and economic viability of railway systems, especially in multimodal transport scenarios.

Recent research in this domain has explored various facets of this issue, incorporating advanced analytical models, simulation techniques, and practical implementations to improve the distribution of empty wagons [1–5].

Let us move on to constructing territorial schemes for the efficient use of rolling stock. The real transport situation in the geometric Euclidean (GEM) model is “idealized” in the sense that the Euclidean distances between their beginnings and ends are taken as route lengths [4]. Then the line delimiting their “territories of influence” is written by the equation:

$$p_1 + q_1 \sqrt{x^2 + y^2} = p_2 + q_2 \sqrt{(x-L)^2 + y^2} \quad (1)$$

Equation (1) defines an algebraic line on the plane, generally speaking, of the fourth order. This line is a Descartes oval with foci located at the points O (0,0) and A (L,0).

The result of constructing a geometric Euclidean model (GEM) serves as a theoretical basis for creating a real geometric routing model (GMM) using the coefficient of non-linearity of routes (k_i). As a result, it is possible to identify zones within whose boundaries transportation is most effective, taking into account geographical, economic, and infrastructure factors. As in the GEM, the «areas of influence» of the duopolists are delimited by a line that is determined by the cost of freight transportation from their locations to destinations. The equation of this line in the RGM has the form:

$$p_1 + q_1 k_1 \sqrt{x^2 + y^2} = p_2 + q_2 k_2 \sqrt{(x-L)^2 + y^2} \quad (2)$$

Numerical data for modeling are presented in Table 1.

Table 1

Numerical data for departure stations

Port station	p_i	q_i	k_i
Zarechnaya	494,564	27,120	1,425
Azov	542,506	27,196	1,504
Taganrog	674,046	26,871	1,541
Yesk	1122,202	25,260	1,517

Modeling options for objects and corresponding parameters of the transport market are presented in the figures 1 and 2.

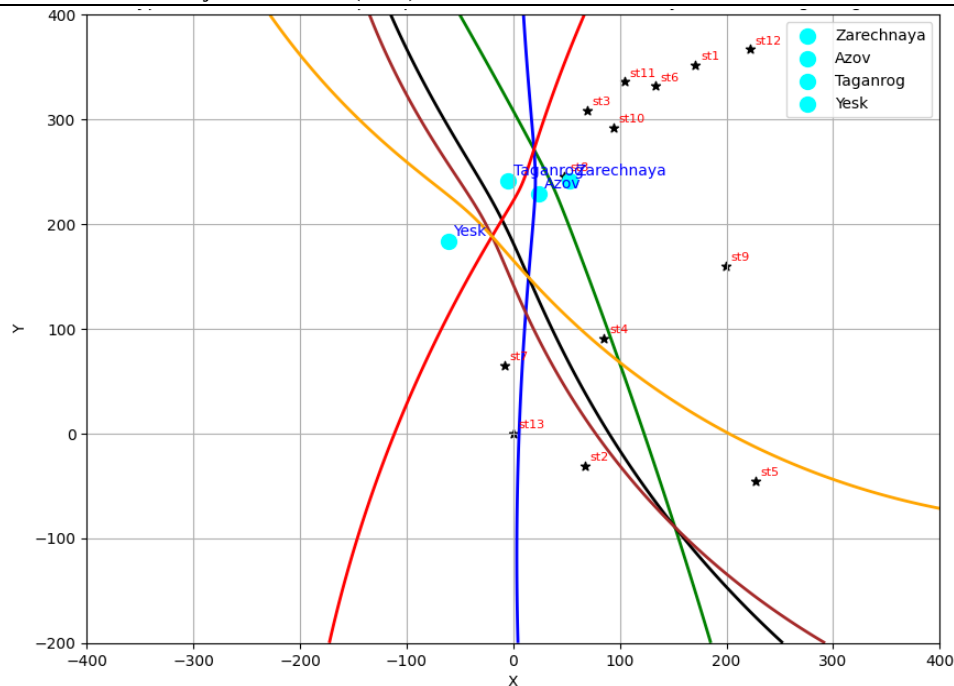


Figure 1. Delimitation of a part of a polygon into «areas of influence» of departure stations in duopolistic situations with $k=1$ (GEM)

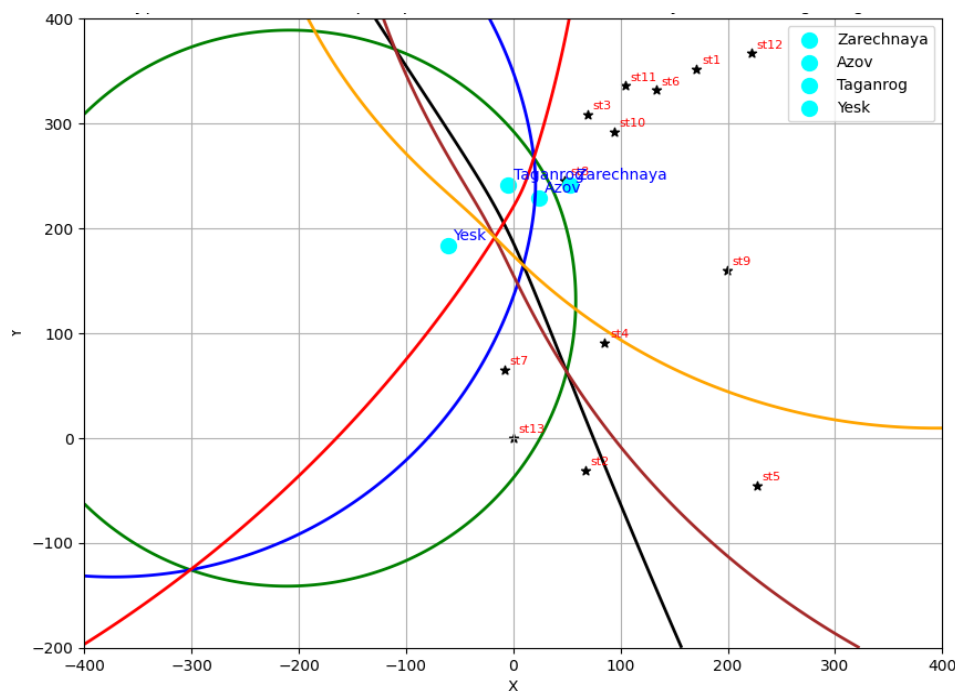


Figure 2. Delimitation of a part of a polygon into «areas of influence» of departure stations in duopolistic situations (GMM)

The delineation of economic-geographical boundaries of «areas of influence» around departure stations is a crucial aspect of transport and logistics planning, especially in the context of railway networks where the oligopolistic nature of the freight market can significantly impact operational efficiency and competitive dynamics. The introduction of the route non-linearity coefficient into these studies marks a significant advancement in the precision of modeling these influence zones.

By integrating the route non-linearity coefficient, the GEM enables researchers and planners to map the

areas of influence around railway stations with enhanced precision. This model takes into account factors such as track curvature, service interruptions, and mandatory stop points, which all influence the actual route a freight journey might take. Consequently, this leads to a more accurate depiction of how freight flows are controlled and influenced by specific departure stations within the railway network.

Acknowledgements

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MATHEMATICS

USING TEST TASKS TO INCORPORATE NEW KNOWLEDGE AND METHODS OF ACTION INTO THE PAST EXPERIENCE OF STUDENTS IN SECONDARY SCHOOLS

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Abstract

The article draws attention to the importance of using test tasks in incorporating new knowledge and methods of activity into the past experience of students in secondary schools. Examples of systematized versions of test tasks applied with the aim of developing students' knowledge, skills and habits, studying the level of development in this direction and implementing the process of strengthening with variable rules are given.

The research paper presents a summary of the psycho-didactic requirements that must be considered when selecting test tasks as a means of organizing the learning activities of students in general education schools, especially their independent work.

Keywords: actualization of past experience; subsystem; test; independent work; psycho-didactic requirements; analytical and heuristic activity; structure.

Relevance of the topic. The lack of clarity of psycho-didactic requirements that must be observed when formulating test tasks as a means of organizing the learning activities of students in general education schools, especially their independent work, negatively affects the activities of practitioners, leading to errors in the selection and application of the aforementioned training tools adequate to specific conditions. Based on this reason, we conclude that the research topic is relevant.

Methodological basis of the study. In the process of conducting the research, the "System-structural approach", which originated from L. Bertalanfi's idea of "System Analysis" [3;8] and was formed as an important branch of dialectics and rose to the level of its alternative, scientific-theoretical and theoretical methods of scientific cognition, the internal relationships of the forms of scientific cognition, and various pedagogical and psychological research generalizations were used as a methodological basis.

Interpretation of research materials. "One of the main and fundamental issues in modern educational theory is the problem of the structure of the process of knowledge acquisition and its dependence on what. Many studies have revealed and proven that this depends on the logical structure of the educational process itself" [1;128]. In the course of our research, which has been conducted for many years, the psycho-didactic, philosophical-methodological and logical foundations of action projects that proceed in accordance with the paths of knowledge and methods of action that have a special place in human experience and are included in the perfect learning system as subsystems have been formed. In our opinion, while in the "explanatory-productive subsystem" knowledge and methods of action are mainly presented to students in general education schools by the teacher, in the "subsystem based on problem-based learning" students acquire them through independent search. Since the subsystems in question

belong to the same system, the didactic system in both cases (if we do not take into account the degree of activity of the teacher and the student) is the same (the internal and methodological substructures in the organization of these subsystems differ from each other). Thus, past experience is actualized, new knowledge and methods of action are learned, and finally, they are strengthened by incorporating them into past experience. (For more detailed information, see: [11-12]) In both subsystems, the application of tests is useful in actualizing the past experience of students and incorporating new knowledge (or methods of action) into their current experience. Because the use of tests creates favorable conditions for independent work of students in accordance with these goals.

Tests applied for the purpose of updating knowledge and methods of action are applied both as part of homework (or as a whole, covering homework), and in connection with determining the level of learning of the previous topic by students, and also at the first (initial) stage of mastering new material, and this has an effective effect on the results of training. Also, different levels of incorporating new knowledge and methods of action into previous experience can be covered in tasks (at the same time in tests), which serves to solve most of the tasks set before the educational process [10].

It is worth emphasizing that it is possible to benefit from tests in the application of all types of independent work, which are considered as carriers of new quality (let's not forget that when the opportunity becomes an action, a new quality is formed. See: [5]). However, it would be wrong to talk about an effective learning process outside of independent work. When we base this argument on this, we mean an independent work system and its nomenclature, which functions as a carrier of new quality, which realizes the possibilities of this process, in accordance with the logic of the learning

process, and we consider it a correct approach to understand independent work as a subsystem of the activity of the student (the learner, who is the subject of the goal of mastering the necessary part of human experience in a general education school), who acts as the main component (participating in the system) in the learning process. In our opinion, in the learning process, the subsystem of his activity, characterized by the fulfillment of the teacher's task without direct assistance, corresponding to the degree of independence of the student, is his independent work. (For more information, see [7]).

Here, let us illustrate our point by presenting two versions of test samples of this type (selected as a means of independent activity for students to actualize their past experience and incorporate new knowledge and methods of action into their experience).

After studying the material on "Planimetry Axioms" included in the "Geometry Content Line", students (in general schools, "students" and "students" are used as synonymous concepts - FN, KS) can use the tests below (as independent work) to study, apply, and strengthen the level of development of their knowledge, skills, and habits.

Option I

1. Points A, B, and C lie on a straight line. Segment BC is 3 times longer than segment AC. Segment AB is 3.6 cm shorter than segment BC. Find the length of segment AC.

- A) 2.4 cm B) 3.6 cm C) 1.2 cm D) 10.8 cm

2. The angle between rays m and c is 157° . The angle between rays n and c is 39° greater than the angle between rays m and n. If ray n passes between rays m and c, find $\angle(nc)$. The angle between the rays and is .

- A) 98° ; B) 108° ; C) 54° ; D) 59° .

3. Five points are marked on a plane: A,B,C,D,E. A straight line m divides this plane into two half-planes such that three of the marked points lie in one of these half-planes and two in the other. How many times can the broken straight line ABCDE intersect the straight line m?

- A) 1,3,5 times; B) 1,2,3,4,5 times; C) 1,2,3,4 times; D) does not cut.

4. How many triangles are there that are equal to the given triangle and whose two vertices coincide with the two vertices of this triangle that lie on the straight line β ? (Figure 1)

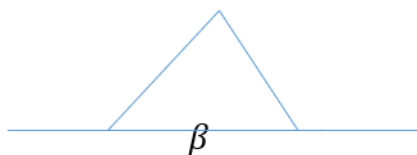


Figure 1.

- A) 1; B) 2; C) 3; D) 4.

5. Points K, P and M lie on a straight line and $MK=5.4$ cm, $KP=8$ cm. Find the length of the straight line segment MP.

- A) 2,6 cm; B) 13,4cm C) 2,6 cm and 13,4cm; D) 5,4 cm.

6. Six points are marked on a straight line: A, B, C, D, E, F. How many straight line segments are there whose endpoints are the given points?

- A) 10; B) 5; C) 15; D) 12.

7. Into how many parts can three different straight lines divide a plane?

- A) 4,5,6 parts; B) 4,6,7 parts; C) 4,5,6,7 parts; D) 3,4,5,6 parts. [6; p.17]

Option II

1. Points C, D, and E lie on a straight line. Segment DE is twice as short as segment CD. Segment CD is 4.8 cm shorter than segment CE. Find the length of segment DE. Points C, D and E lie on a straight line.

- A) 2.4 cm; B) 9.6 cm C) 4.8 cm D) 3.2 cm

2. The angle between rays a and b is 143° . The angle between rays a and c is 29° smaller than the angle between rays b and c. If ray c passes between rays a and b, find $\angle(bc)$.

- A) 59° ; B) 114° ; C) 57° ; D) 86° .

3. Four points are marked on the plane: M, N, P, K. The straight line ρ divides this plane into two half-planes such that two of the marked points lie in one of these half-planes and two in the other. How many times can the broken straight line MNPK intersect the straight line ρ ?

- A) 1, 2; B) 1, 2, 3; C) 1, 2, 3, 4; D) 2, 3.

4. How many triangles are there that are equal to the given triangle and whose two vertices coincide with the two vertices of this triangle that lie on the straight line ρ ? (Figure 3)

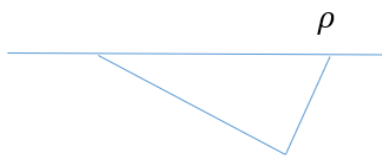


Figure 3

- A) 4; B) 2; C) 1; D) 3.

5. Points B, C and D lie on a straight line and $BC=9$ cm, $CD=6.7$ cm. Find the length of the straight line segment BD.

- A) 2.3 cm B) 15,7 cm C) 2.3 cm and 15.7 cm D) 6.7 cm

6. How many straight lines are there that pass through two of the six given points, no three of which lie on the same straight line?

- A) 15; B) 12; C) 6; D) 30.

7. Into how many parts can four different straight lines divide a plane?

- A) 9; B) 10; C) 11; D) 12.

These tests can be used for another purpose, namely, to help students acquire new knowledge, specifically, to actualize the necessary experience for familiarization with the axioms of stereometry contained in the "Geometry content line". It is best to present these tests to students as homework before teaching "Axioms of Stereometry" and begin the lesson with an analysis of the results of that task, that is, the process of checking the homework should coincide with the actualization process.

In order to integrate new knowledge and methods of action into past experience and turn them into a system, generalization tests, which cover both individual topics and entire titles (teaching units, chapters), play an important role in realizing the capabilities of students in secondary schools. The following is an example of such tests - in order to integrate the knowledge, skills and habits acquired in the teaching of the topic "Reduction of Fractions" into the student's existing experience and turn them into a system, tests can be applied as independent work material in two versions.

1. At what value of x does the fraction $\frac{x-2}{x^2+4}$ become zero?

- A) $x = 4$; B) $x = 3$; C) $x = 2$; D) $x = -2$; E) $x = 0$.

2. Find the possible values of the variable x in the fraction $\frac{6x+7}{1,8-x}$

- A) $x = 1,8$; B) $x \neq 1,8$; C) $x \neq 2$; D) $x = 0$; E) $x = -\frac{7}{6}$

3. Find the possible values of the variables in the expression. $\frac{a}{a-b} - \frac{b}{a+b}$

- A) $a \neq b$; B) $a \neq -b$; C) $a = b$; D) $a = -b$; E) $a \neq \pm b$.

4. Find the possible values of the variables in the expression. $\left(\frac{a}{a^2-ab} - \frac{b}{b^2-ab}\right) : (a+b)$

- A) $a \neq 0, b \neq 0$; B) $a \neq 0, a \neq b$; C) $a \neq \pm b$;

- D) $a \neq 0, b \neq 0, a \neq \pm b$; E) $a \neq \pm b, a \neq 0$.

5. Which of the following equations is equivalent to the fraction $\frac{a}{b}$? $\frac{-a}{b}$; $\frac{-a}{-b}$; $-\frac{a}{b} - \frac{a}{-b}$; $-\frac{a}{-b}$ ($a \neq 0, b \neq 0$)?

- A) 4; B) 2; C) 3; D) 5; E) 6.

6. Which of the following fractions is equivalent to the fraction $\frac{a-b-c}{a+b-c}$

$$\frac{b+c-a}{c-b-a}; \frac{b+c-a}{a+b-c}; -\frac{b+c-a}{a+b-c}; -\frac{b+c-a}{c-b-a}; -\frac{b+c-a}{c+b-c}?$$

- A) 1; B) 2; C) 3; D) 4; E) none.

7. If a, b, c, d are consecutive even natural numbers, calculate the value of the expression $\frac{b-a}{c-b}$

- A) 2; B) 3; C) 4; D) 1; E) 5.

8. Reduce the fraction: $\frac{3a-3}{a^2-1}$

- A) $\frac{3}{a-1}$; B) $\frac{3}{a+1}$; C) $\frac{3a}{a-1}$; D) $\frac{3a}{a-1}$; E) $\frac{a-1}{3}$.

9. Reduce the fraction: $\frac{9-6x+x^2}{x^2-9}$

- A) $\frac{3-x}{x+3}$; B) $\frac{x+3}{x-3}$; C) $\frac{x-3}{x+3}$; D) $\frac{x+3}{3-x}$; E) $\frac{x+3}{x-9}$

10. Reduce the fraction: $\frac{(a^2-1)^2+4a^2}{a^4-1}$

- A) -1; B) $\frac{5a^2-1}{a^2+1}$; C) $\frac{a^2+1}{a^2-1}$; D) $\frac{5a^2-1}{a^2+1}$; E) $\frac{a^4+1}{a^4-1}$.

11. If $a^2 = 40 + b$ and $b^2 = 8 + a$ and, find the value of the expression. $\frac{a^2-ab-a^2b+b^2}{ab^2-a^2-b^2+ab}$

- A) 1; B) 2; C) -2; D) 5; E) -5.

12. Reduce the fraction: $\frac{(m-1)^3-8}{3m^2-18m+27}$

- 13 A) $\frac{m^2-3}{m-3}$; B) $\frac{m^2+3}{3(m-3)}$; C) $\frac{m^2+3}{3}$; D) $\frac{3}{m^2+3}$; E) $\frac{m^2+3}{m-3}$.

13. Reduce the fraction: $\frac{b^{45}+1}{b^3-b^{18}+b^{33}}$

A) $\frac{b^{15}+1}{b^3}$; B) $\frac{b^{30}+1}{b^3}$; C) $\frac{b^{15}+1}{b^6}$; D) $\frac{b^{30}+1}{b^6}$; E) $\frac{b^{15}+1}{b^9}$. [4; s. 61-71]

The following are examples of final tests applied at the end of the teaching work on "Expressions with Variables", "Linear Function", "Force", "Properties of Force", and "Operations on Polynomials" (two examples of variants).

Option I

1. Calculate the value of the expression if $a = 6, b = -11, c = -10$ $b^2 - 4bc$

A) 452; B) -202; C) -404; D) 476.

2. Calculate the value of the expression if $x = -0,8$;

$$-0,5(3x - 4) - 1,5(6 + 5x)$$

A) -0.4; B) 0.2; C) 0.4; D) -0.2.

3. Solve the equation. $5 - 2(3x - 4) = 4x - 3$

A) 1.6; B) -1.6; C) $\frac{5}{8}$; D) $-\frac{5}{8}$.

4. Two typists typed a 97-page manuscript. The first typist worked for 4 hours and the second typist for 5 hours. If the two typists together typed 22 pages per hour, how many pages did the second typist type in 1 hour?

A) 14 pages; B) 13 pages; C) 9 pages; D) 8 pages.

5. Simplify the expression. $\frac{(-1,5x^2y)^3(2y^3)^4}{(6x^3y^2)^2}$

A) $-1,5x^4y^{11}$; B) $-2,5x^4y^{11}$; C) $-1,5x^6y^{11}$; D) $-1,5x^4y^8$.

6. Solve the equation. $\frac{2x-3}{4} - \frac{5x+2}{6} = 3$

A) $-\frac{4}{49}$; B) -12,25; C) -11,5; D) 12,25.

7. Simplify the expression. $(3x - 2)(2x - 1) - (5x + 2)(3x - 4)$

A) $-9x^2 + 7x - 10$; B) $-9x^2 - 7x + 10$; C) $-9x^2 + 7x + 10$; D) $-9x^2 - 7x - 10$.

8. The graph of the function $y=x/3+2$ intersects the abscissa at (m;0) and the ordinate at (0;n). Find the sum of m+n.

A) 6; B) 4; C) -2; D) -4.

9. The gardener walked from the garden to the shop along the village road at a speed of 5 km/h, and returned along the forest road at a speed of 3 km/h. He spent 8 minutes less time returning. The forest road is 2 km shorter than the village road. Find the distance the gardener traveled.

A) 12 km; B) 6 km; C) 8 km; D) 10 km.

Option II

1. Calculate the value of the expression if

$$a = 7, b = -8, c = -12 \quad b^2 - 4bc$$

A) 413; B) -370; C) -433; D) -335.

2. Calculate the value of the expression if $x = -\frac{2}{3}$;

$$-2,5(4x - 3) - 0,5(5 - 2x)$$

A) -4; B) -2; C) -3; D) -4.5.

3. Solve the equation. $3 - 4(2x - 5) = 2 - 6x$

A) $\frac{2}{21}$; B) 8,5; C) 10,5; D) 12.

4. Two stamping machines produced 188 parts. The first machine worked for 6 hours and the second machine for 4 hours. If the two machines produced 39 parts in 1 hour, how many parts can be produced in 1 hour on the second machine?

A) 18; B) 21; C) 16; D) 23.

5. Simplify the expression. $\frac{(-0,5y^3x)^2(2x^2y)^3}{(\frac{1}{3}x^5y^3)^2}$

A) $\frac{18y^3}{x^2}$; B) $\frac{9y^3}{x^2}$; C) $\frac{18y^2}{x^2}$; D) $\frac{18y^3}{x}$.

6. Solve the equation. $\frac{3x-1}{6} - \frac{2x+3}{8} = 2$

A) $\frac{6}{61}$; B) $10\frac{1}{6}$; C) $-10\frac{1}{6}$; D) $10\frac{1}{3}$.

7. Simplify the expression. $(4x - 3)(3x + 2) - (1 - 2x)(5 - 3x)$

A) $6x^2 + 12x + 11$; B) $-6x^2 - 12x + 11$; C) $6x^2 - 12x - 11$; D) $6x^2 + 12x - 11$.

8. The graph of the function $y=-1.5x-2$ intersects the abscissa at (a;0) and the ordinate at (0;b). Find the sum of a+b.

A) -2; B) $-2\frac{1}{3}$; C) $-3\frac{1}{3}$; D) -2,5.

9. A pedestrian walked to the forest at a speed of 4 km/h through the countryside, and returned at a speed of 3 km/h along the highway. It took him 45 minutes longer to get back. The highway is 2 km longer than the countryside road. Find the distance the pedestrian traveled

A) 4 km; B) 6 km; C) 8 km; D) 10 km. [2; 19-20]

Through the processing of the information obtained during the research process, it was concluded that when selecting test tasks as a means of organizing students' learning activities, especially their independent work, it would be useful to anticipate the following psycho-didactic requirements:

* Test tasks should be selected and systematized based on the tasks ahead. The system of applied test tasks should include two important aspects:

1) The general goal of the educational process: a) the logic of assimilating the experience that humanity has acquired in the process of its historical development; b) the practice of preserving what has been achieved; c) the method of orientation towards the preparation for the acquisition of creative experience necessary for the civilization and freedom of man and the society to which he belongs; d) the norms of orientation towards the acquisition of qualities that condition the coexistence of people, which are organically connected with the previous three goals, and the opening of the window to the world for him;

2) Transforming the training process into a well-managed process.

It is necessary to determine the point of application of the test in the learning process and the form of coverage of students. In our opinion, test tasks can be applied at all stages of the learning process: a) during the justification of learning and updating of past experience; b) during the acquisition of knowledge; c) during the application and systematization of knowledge, skills and habits; d) during the assessment of the process and results by the teacher and the student himself. According to the form of coverage of students: individual; pair; group; frontal.*

The duration of the test tasks, their coverage of previous knowledge, the level of difficulty of the new tasks to be determined, and their suitability for the student's potential should be determined.*

The teacher should consider the type and form of the test task; the conditions and requirements of the task should be clear; the student should be given necessary and clarifying instructions for their activity.*

Consistency, systematicity, students' cognitive development style, dynamics, its stages, individual and age characteristics should be taken into account in the application of test tasks.*

It is important to include enabling moments and new elements in test tasks for generalization, systematization, and application of knowledge in a changed situation; the implementation of tasks should be based on the students' acquired knowledge, habits and skills, life experiences, and observations, and the student should be directed towards acquiring more general knowledge, skills, habits, and experience.*

Test tasks should, with their content, fun, and logic, create and develop the student's interest in learning.*

Test tasks should encourage the formation of the student's ability to make accurate and fair assessments, which is considered one of the most important personal qualities.*

The system of test tasks should maintain the unity of mental and practical activity. During the execution of test tasks, the working conditions should be improved with the correct guidance of the teacher in order to develop the analytical and heuristic aspects of the student's mental activity in unity, to form his own activity as a subject of management. The teacher should continuously adjust the management work in accordance with specific conditions. [5; 58-59]*

Scientific novelty of the research. The research work identified psycho-didactic requirements that should be considered when formulating test tasks as a means of organizing students' learning activities, especially their independent work.

Practical significance of the research. Determining the psycho-didactic requirements that must be observed when formulating test tasks as a means of organizing students' learning activities, especially their independent work, will play a positive role in eliminating errors made in the activities of practical educators.

Result. When applying test tasks as a means of organizing and managing students' learning activities, especially their independent work, it is possible to positively influence (improve) the quality of the learning process by meeting psycho-didactic requirements.

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THE INITIAL-BOUNDARY VALUE PROBLEM FOR A NONSTATIONARY THIRD-ORDER COMPOSITE TYPE EQUATION ON A PLANE

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Abstract

This paper presents a study of a boundary value problem for a linear third-order equation with multiple characteristics in a plane. The unique solvability of this problem is established using the energy method. The Green function was constructed to prove the existence of a solution to this problem.

Keywords: uniqueness, existence, system of integral equations, The Green function.

Introduction

In a line the following equation refers to poorly studied odd-order equations

$$L(u) \equiv u_{xxx} - u_t = f(x, y, u, u_x, u_{xx}), \quad u = u(x, t), \quad (MC)$$

which is called an equation with multiple characteristics (MC). (see[2])

The well-known Korteweg-de Vries equation (KdV)

$$u_y + uu_x + \beta u_{xxx} = 0 \quad (KdV)$$

which is the object of research by many authors and occupies an important place in the study of nonlinear wave propagation in weakly dispersive media [3 – 7].

The Korteweg–de Vries (KdV) equation describes the evolution of weakly nonlinear long-wavelength excitations in a medium with dispersion in the high-frequency domain. The KdV equation finds applications in diverse fields, such as fluid dynamics (e.g., modeling gravitational waves in shallow water and nonlinear Rossby waves), plasma physics (e.g., describing ion-acoustic waves), electrical engineering (e.g., analyzing nonlinear circuits), and even epidemiology (e.g., simulating the time evolution of infected individuals during an epidemic), etc. [3 – 7].

Reference [2] established a foundational framework for the equation,

$$u_{xxx} - u_t = 0, \quad (LKdV)$$

including the construction of a fundamental solution, the development of potential theory, and a methodology for addressing boundary value and Cauchy problems.

The solutions of equation

$$u_{xxx} + u_{yyy} - u_t = 0 \quad (1)$$

and the linear Zakharov-Kuznetsov equation (equations, as referenced in [12 - 14])

$$u_t + u_{xxx} + u_{yyy} = 0 \quad (LZK)$$

exhibit similar asymptotic behavior at infinity.

As a multidimensional generalization of the Korteweg-de-Vries equation, the Zakharov-Kuznetsov equation (LZK) describes ion-acoustic wave propagation in plasma [14].

A fundamental solution for equation (1) within the space R^{n+1} was constructed in [1].

The first paper addressing the initial-boundary value problem of the Korteweg-de Vries (KdV) equation on the finite interval (0,1) was by Bubnov in 1979 [8], who considered the initial-boundary value problem with general linear boundary conditions. Since then, numerous authors have worked on improving existing results and presenting new findings in recent years [12 – 13].

The initial-boundary value problem of the Zakharov-Kuznetsov equation was studied in [15 – 17].

The relevance of studying boundary value problems for odd-order equations with multiple characteristics is underscored by these and other practical applications. It's worth noting that certain linear boundary value problems for linear third-order equations with multiple characteristics have been explored in [2, 9 - 11] in a line.

This paper employs a linear boundary value problem for a linear third-order equation with multiple characteristics in a plane.

Statement of the problem

Problem A. It is required to determine in domain $D = \{(x, y, t) : 0 < x < 1, 0 < y < 1, 0 < t \leq T\}$ function $u(x, y, t)$ that has the following properties:

$$1) u(x, y, t) \in C_{x,y,t}^{3,3,1}(D) \cap C_{x,y,t}^{2,2,0}(\overline{D});$$

2) which is a regular solution to the following equation:

$$L(u) \equiv u_{xxx} + u_{yyy} - u_t = f(x, y, t) \quad (1)$$

in domain D;

3) satisfying the following conditions

$$u(x, y, 0) = u_0(x, y), \quad 0 \leq x \leq 1, 0 \leq y \leq 1, \quad (2)$$

$$u(0, y, t) = \varphi_0(y, t), \quad 0 \leq y \leq 1, 0 \leq t \leq T, \quad (3)$$

$$u_x(0, y, t) = \varphi_1(y, t), \quad 0 \leq y \leq 1, 0 \leq t \leq T, \quad (4)$$

$$u(1, y, t) = \varphi_2(y, t), \quad 0 \leq y \leq 1, 0 \leq t \leq T, \quad (5)$$

$$u(x, 0, t) = \psi_0(x, t), \quad 0 \leq x \leq 1, 0 \leq t \leq T, \quad (6)$$

$$u_y(x, 0, t) = \psi_1(x, t), \quad 0 \leq x \leq 1, 0 \leq t \leq T, \quad (7)$$

$$u(x, 1, t) = \psi_2(x, t), \quad 0 \leq x \leq 1, 0 \leq t \leq T, \quad (8)$$

and matching conditions

$$u_0(0, 0) = \varphi_0(0, 0) = \psi_0(0, 0), \quad u_{0x}(0, 0) = \varphi_1(0, 0), \quad u_{0y}(0, 0) = \psi_1(0, 0),$$

$$u_0(1, 0) = \varphi_2(0, 0), \quad u_0(0, 1) = \psi_2(0, 0).$$

Uniqueness of the solution

Theorem (Uniqueness of solution). Then the solution to Problem A is unique.

Proof. Let there be two solutions to the considered problem, u_1 and u_2 . Consider their difference $w = u_1 - u_2$. With regard to w , we obtain the following problem:

$$L(w) \equiv w_{xxx} + w_{yyy} - w_t = 0 \quad (10)$$

$$w(x, y, 0) = 0, \quad 0 \leq x \leq 1, \quad (20)$$

$$w(0, y, t) = 0, \quad 0 \leq y \leq 1, 0 \leq t \leq T, \quad (30)$$

$$w_x(0, y, t) = 0, \quad 0 \leq y \leq 1, 0 \leq t \leq T, \quad (40)$$

$$w(1, y, t) = 0, \quad 0 \leq y \leq 1, 0 \leq t \leq T, \quad (50)$$

$$w(x, 0, t) = 0, \quad 0 \leq x \leq 1, 0 \leq t \leq T, \quad (60)$$

$$w_y(x, 0, t) = 0, \quad 0 \leq x \leq 1, 0 \leq t \leq T, \quad (70)$$

$$w(x, 1, t) = 0, \quad 0 \leq x \leq 1, 0 \leq t \leq T. \quad (80)$$

Let us prove that $w(x, y) \equiv 0$.

Having integrated the following identity

$$e^{-t} w(x, y, t) L(w) \equiv e^{-t} w(w_{xxx} + w_{yyy} - w_t) = 0 \quad (9)$$

over domain D , taking into account boundary conditions (20) - (80),

$$\begin{aligned} & -\frac{1}{2} \int_0^1 \int_0^T e^{-t} w_x^2 \Big|_{x=1} dt dy - \frac{1}{2} \int_0^1 \int_0^T e^{-t} w_y^2 \Big|_{y=1} dt dx - \\ & -\frac{1}{2} \int_0^1 \int_0^1 e^{-t} w^2 \Big|_{y=1} dy dx - \frac{1}{2} \int_0^1 \int_0^1 \int_0^T e^{-t} w^2 dx dy dt = 0. \end{aligned} \quad (10)$$

Then from (11) we obtain the following conditions:

$$\begin{cases} w_x(1, y, t) = 0, & 0 \leq y \leq 1, 0 \leq t \leq T, \\ w_y(x, 1, t) = 0, & 0 \leq x \leq 1, 0 \leq t \leq T, \\ w(x, y, 1) = 0, & 0 \leq x \leq 1, 0 \leq y \leq 1, \\ w(x, y, t) = 0, & (x, y, t) \in D. \end{cases}$$

Due to continuity $w(x, y, t)$ in $\overline{D}$ we have $w(x, y, t) = 0$.

Existence of the solution

Theorem. Let the following conditions be satisfied:

$$u_0(x, y) \in CVL_{x,y}[0;1], \quad \varphi_0(x, y) \in C_{x,y}^{1,1}[0,1],$$

$$\varphi_1(x, y) \in C[0,1], \quad \varphi_2(x, y) \in C_{x,y}^{0,1}[0,1],$$

$$\psi_0(x, y) \in C_{x,y}^{1,1}[0,1], \quad \psi_1(x, y) \in C_{x,y}^{1,0}[0,1], \quad \psi_2(x, y) \in C_{x,y}^{1,0}[0,1],$$

where CVL stands for a space of functions with Continuous Variation and Limited total variation

$$f(x, y, t) \in C(\overline{D}), \quad \frac{\partial f(x, y, t)}{\partial t} \in C(\overline{D}), \quad f(x, y, 0) = \frac{\partial f(x, y, 0)}{\partial t} = 0.$$

Then the solution to problem (1) - (8) exists.

Let us construct the Green function for problem A.

The following identity holds:

$$zL(q) - qM(z) = \frac{\partial}{\partial \xi} \left\{ \sum_{k=0}^2 (-1)^k \frac{\partial^k z}{\partial \xi^k} \frac{\partial^{2-k} q}{\partial \xi^{2-k}} \right\} + \frac{\partial}{\partial \eta} \left\{ \sum_{k=0}^2 (-1)^k \frac{\partial^k z}{\partial \eta^k} \frac{\partial^{2-k} q}{\partial \eta^{2-k}} \right\} - \frac{\partial}{\partial \tau} (zq), \quad (11)$$

where $M \equiv -\frac{\partial^3}{\partial \xi^3} - \frac{\partial^3}{\partial \eta^3} + \frac{\partial}{\partial \tau}$ is the operator conjugate to operator $L \equiv \frac{\partial^3}{\partial \xi^3} + \frac{\partial^3}{\partial \eta^3} - \frac{\partial}{\partial \tau}$, and

$z(\xi, \eta, \tau)$ and $q(\xi, \eta, \tau)$ are rather smooth functions.

Integrating identity (11) over domain D, we obtain

$$\begin{aligned} \iiint_D (zL(q) - qM(z)) d\xi d\eta d\tau &= \int_{\Gamma} \left(\sum_{k=0}^2 (-1)^k \frac{\partial^k z}{\partial \xi^k} \frac{\partial^{2n-k} q}{\partial \xi^{2n-k}} \right) d\eta d\tau + \\ &+ \left(\sum_{k=0}^2 (-1)^k \frac{\partial^k z}{\partial \eta^k} \frac{\partial^{2n-k} q}{\partial \eta^{2n-k}} \right) d\xi d\tau - (zq) d\xi d\eta, \end{aligned} \quad (12)$$

where $\Gamma = \partial D$.

Now, in formula (12), for functions q and z , we take functions

$u(x, y, t)$ - any regular solution to equation $Lu = f(x, y, t)$ and $U(x, y, t; \xi, \eta, \tau)$ - fundamental solution to equation $Lu = 0$.

$$U(x, y; \xi, \eta) = (t - \tau)^{-\frac{2}{3}} f\left(\frac{x - \xi}{(t - \tau)^{\frac{1}{3}}}\right) f\left(\frac{y - \eta}{(t - \tau)^{\frac{1}{3}}}\right), \quad x \neq \xi, \quad y \neq \eta, \quad t > \tau. \quad (13)$$

Function

$$f(s) = \int_0^{+\infty} \cos(\lambda^3 - \lambda s) d\lambda, \quad -\infty < s < +\infty,$$

called Airy functions, satisfy the following equation ([1]):

$$z''(s) + \frac{1}{3} sz(s) = 0. \quad (14)$$

Let domain D^ε be defined by the following inequality:

$$D^\varepsilon = \{(\xi, \eta, \tau): 0 \leq \xi \leq 1, 0 \leq \eta \leq 1, 0 < \tau \leq t - \varepsilon\},$$

where $\varepsilon > 0$ is a sufficiently small number. Then identity (12) with regard to D^ε takes the following form:

$$\begin{aligned} \iiint_{D^\varepsilon} U(x, y, t; \xi, \eta, \tau) f(\xi, \eta, \tau) d\xi d\eta d\tau &= \int_0^1 \int_0^{y-\varepsilon} \sum_{k=0}^2 (-1)^k \frac{\partial^k U}{\partial \xi^k} \frac{\partial^{2n-k} U}{\partial \xi^{2n-k}} \Big|_{\xi=0}^{\xi=1} d\tau d\eta + \\ &+ \int_0^1 \int_0^{y-\varepsilon} \sum_{k=0}^2 (-1)^k \frac{\partial^k U}{\partial \eta^k} \frac{\partial^{2n-k} U}{\partial \eta^{2n-k}} \Big|_{\xi=0}^{\xi=1} d\tau d\xi - \int_0^1 \int_0^1 (Uu) \Big|_{\tau=0}^{\tau=t-\varepsilon} d\xi d\eta. \end{aligned}$$

Here as ε tends to zero and considering the following equality ([1])

$$\lim_{\varepsilon \rightarrow 0} \int_0^1 \int_0^1 U(x, y, t; \xi, \eta, t - \varepsilon) u(\xi, \eta, t - \varepsilon) d\xi d\eta = \pi^2 u(x, y),$$

we obtain

$$\begin{aligned} \pi^2 u(x, y, t) &= \int_0^t \int_0^1 \sum_{k=0}^2 (-1)^k \frac{\partial^k U}{\partial \xi^k} \frac{\partial^{2-k} u}{\partial \xi^{2-k}} \Big|_{\xi=0}^{\xi=1} d\eta d\tau + \int_0^t \int_0^1 \sum_{k=0}^2 (-1)^k \frac{\partial^k U}{\partial \xi^k} \frac{\partial^{2-k} u}{\partial \xi^{2-k}} \Big|_{\eta=0}^{\eta=1} d\xi d\tau + \\ &+ \int_0^1 \int_0^1 U(x, y, t; \xi, \eta, 0) u(\xi, \eta, 0) d\xi d\eta - \iiint_D U(x, y, t; \xi, \eta, \tau) f(\xi, \eta, \tau) d\xi d\eta d\tau. \end{aligned} \quad (15)$$

Let now $W(x, y, t; \xi, \eta, \tau)$ be any regular solution to the following equation:

$$-v_{\xi\xi\xi} - v_{\eta\eta\eta} + v_\tau = 0, \quad (16)$$

and $u(x, y, t)$ is any regular solution to equation $Lu = f(x, y, t)$. Now, assuming in formula (12) that $z = W(x, y, t; \xi, \eta, \tau)$, $q = u(x, y, t)$, we have

$$\begin{aligned} \iint_D W(x, y, t; \xi, \eta, \tau) f(\xi, \eta, \tau) d\xi d\eta d\tau &= \int_0^t \int_0^1 \sum_{k=0}^2 (-1)^k \frac{\partial^k W}{\partial \xi^k} \frac{\partial^{2-k} u}{\partial \xi^{2-k}} \Big|_{\xi=0}^{\xi=1} d\eta d\tau + \\ &+ \int_0^t \int_0^1 \sum_{k=0}^2 (-1)^k \frac{\partial^k W}{\partial \eta^k} \frac{\partial^{2-k} u}{\partial \eta^{2-k}} \Big|_{\eta=0}^{\eta=1} d\xi d\tau - \int_0^1 \int_0^1 (Wu) \Big|_{\tau=0}^{\tau=t} d\xi d\eta. \end{aligned} \quad (17)$$

From equalities (15) and (17), we find

$$\begin{aligned} \pi^2 u(x, y, t) &= \int_0^t \int_0^1 \sum_{k=0}^2 (-1)^k \frac{\partial^k (U-W)}{\partial \xi^k} \frac{\partial^{2-k} u}{\partial \xi^{2-k}} \Big|_{\xi=0}^{\xi=1} d\eta d\tau + \\ &+ \int_0^t \int_0^1 \sum_{k=0}^2 (-1)^k \frac{\partial^k (U-W)}{\partial \eta^k} \frac{\partial^{2-k} u}{\partial \eta^{2-k}} \Big|_{\eta=0}^{\eta=1} d\xi d\tau + \int_0^1 \int_0^1 W(x, y, t; \xi, \eta, t) u(\xi, \eta, t) d\xi d\eta + \\ &+ \int_0^1 \int_0^1 (U(x, y, t; \xi, \eta, 0) - W(x, y, t; \xi, \eta, 0)) u(\xi, \eta, 0) d\xi d\eta - \\ &- \iiint_D (U(x, y, t; \xi, \eta, \tau) - W(x, y, t; \xi, \eta, \tau)) f(\xi, \eta, \tau) d\xi d\eta d\tau. \end{aligned} \quad (18)$$

If regular solution $W(x, y, t; \xi, \eta, \tau)$ to equation (18) satisfies the following conditions:

$$\left. \begin{aligned} W(x, y, t; \xi, \eta, \tau) \Big|_{\tau=y} &= 0, \\ W \Big|_{\xi=0} &= U \Big|_{\xi=0}, W \Big|_{\xi=1} = U \Big|_{\xi=1}, \\ W_\xi \Big|_{\xi=1} &= U_\xi \Big|_{\xi=1}, W \Big|_{\eta=0} = U \Big|_{\eta=0}, \\ W \Big|_{\eta=1} &= U \Big|_{\eta=1}, W_\eta \Big|_{\eta=1} = U_\eta \Big|_{\eta=1}. \end{aligned} \right\} \quad (19)$$

then from formula (18) we obtain

$$\begin{aligned} u(x, y, t) &= \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\xi\xi} u \Big|_{\xi=1} d\eta d\tau + \frac{1}{\pi^2} \int_0^t \int_0^1 G_\xi u_\xi \Big|_{\xi=0} d\eta d\tau - \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\xi\xi} u \Big|_{\xi=0} d\eta d\tau + \\ &+ \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\eta\eta} u \Big|_{\eta=1} d\xi d\tau + \frac{1}{\pi^2} \int_0^t \int_0^1 G_\eta u_\eta \Big|_{\eta=0} d\xi d\tau - \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\eta\eta} u \Big|_{\eta=0} d\xi d\tau + \\ &+ \frac{1}{\pi^2} \int_0^1 \int_0^1 G u \Big|_{t=0} d\xi d\eta - \frac{1}{\pi^2} \iiint_D G(x, y, t; \xi, \eta, \tau) f(\xi, \eta, \tau) d\xi d\eta d\tau, \end{aligned} \quad (20)$$

where

$$G(x, y, t; \xi, \eta, \tau) = U(x, y, t; \xi, \eta, \tau) - W(x, y, t; \xi, \eta, \tau),$$

or

$$\begin{aligned}
u(x, y, t) = & \frac{1}{\pi^2} \int_0^1 \int_0^1 G(x, y, t; \xi, \eta, 0) u_0(\xi, \eta, 0) d\xi d\eta - \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\xi\xi}(x, y, t; 0, \eta, \tau) \varphi_0(\eta, \tau) d\eta d\tau + \\
& + \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\xi\xi}(x, y, t; 0, \eta, \tau) \varphi_1(\eta, \tau) d\eta d\tau + \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\xi\xi}(x, y, t; 1, \eta, \tau) \varphi_2(\eta, \tau) d\eta d\tau - \\
& - \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\eta\eta}(x, y, t; \xi, 0, \tau) \psi_0(\eta, \tau) d\xi d\tau + \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\eta\eta}(x, y, t; \xi, 1, \tau) \psi_1(\eta, \tau) d\xi d\tau + \\
& + \frac{1}{\pi^2} \int_0^t \int_0^1 G_{\eta\eta}(x, y, t; \xi, 1, \tau) \psi_2(\eta, \tau) d\xi d\tau - \frac{1}{\pi^2} \iint_D G(x, y, t; \xi, \eta, \tau) f(\xi, \eta, \tau) d\xi d\eta d\tau.
\end{aligned} \quad (21)$$

Formula (21) gives a solution to problem B. However, for this, we still need to prove the existence of function $W(x, y, t; \xi, \eta, \tau)$ that satisfies equation (16) and conditions (19).

Function $G(x, y, t; \xi, \eta, \tau)$ we call the Green function of problem B.

Note that for function $G(x, y, t; \xi, \eta, \tau)$ the same estimates as for function $W(x, y, t; \xi, \eta, \tau)$ are true (see [1]).

$$\begin{aligned}
U(x, y, t; \xi, \eta, \tau) = & \begin{cases} (t-\tau)^{-\frac{2}{3}} f\left(\frac{x-\xi}{(t-\tau)^{\frac{1}{3}}}\right) f\left(\frac{y-\eta}{(t-\tau)^{\frac{1}{3}}}\right), & x \neq \xi, y \neq \eta, t > \tau \\ 0, & t \leq \tau. \end{cases} \\
V(x, y, t; \xi, \eta, \tau) = & \begin{cases} (t-\tau)^{-\frac{2}{3}} \varphi\left(\frac{x-\xi}{(t-\tau)^{\frac{1}{3}}}\right) \varphi\left(\frac{y-\eta}{(t-\tau)^{\frac{1}{3}}}\right), & x > \xi, y > \eta, t > \tau, \\ 0, & t \leq \tau. \end{cases}
\end{aligned} \quad (22)$$

Let's define the following functions:

$$\begin{aligned}
f(s) &= \int_0^{+\infty} \cos(\lambda^3 - \lambda s) d\lambda, \quad -\infty < s < +\infty, \\
\varphi(s) &= \int_0^{+\infty} [\exp(-\lambda^3 - \lambda s) + \sin(\lambda^3 - \lambda s)] d\lambda, \quad s = \frac{x-\xi}{(t-\tau)^{\frac{1}{3}}},
\end{aligned}$$

Functions $f(s)$, $\varphi(s)$ called Airy functions, satisfy the following equation (see [1]):

$$z''(s) + \frac{1}{3}sz(s) = 0.$$

The following relations hold for functions $f(s)$, $\varphi(s)$.

$$\begin{aligned}
\int_0^{+\infty} f(s) ds &= \frac{2\pi}{3}, \quad \int_{-\infty}^0 f(s) ds = \frac{\pi}{3}, \quad \int_{-\infty}^{+\infty} f(s) ds = \frac{2\pi}{3}, \quad \int_0^{+\infty} \varphi(s) ds = 0, \\
\int_0^{+\infty} f(s) ds \int_0^{+\infty} f(s) ds &= \frac{4\pi^2}{9}, \quad \int_{-\infty}^0 f(s) ds \int_{-\infty}^0 f(s) ds = \frac{\pi^2}{9}, \\
\int_0^{+\infty} f(s) ds \int_{-\infty}^0 f(s) ds &= \frac{2\pi^2}{9}, \quad \int_{-\infty}^0 f(s) ds \int_0^{+\infty} f(s) ds = \frac{2\pi^2}{9}.
\end{aligned} \quad (23)$$

$$f(0) = \frac{\sqrt{3}}{2} \int_0^{+\infty} e^{-t^3} dt, \quad f'(0) = \frac{\sqrt{3}}{2} \int_0^{+\infty} t \cdot e^{-t^3} dt$$

$$\varphi(0) = \frac{\sqrt{3}}{2} \int_0^{+\infty} e^{-t^3} dt, \quad \varphi'(0) = \frac{\sqrt{3}}{2} \int_0^{+\infty} t \cdot e^{-t^3} dt.$$

and the equality is valid at $s \neq 0$

$$\int_{-\infty-\infty}^{+\infty+\infty} U(x, y, t) dx dy = \int_{-\infty}^{+\infty} f(\zeta) d\zeta \cdot \int_{-\infty}^{+\infty} f(\tau) d\tau = \pi^2. \quad (24)$$

As $s \rightarrow +\infty$

$$\left. \begin{matrix} f^{(v)}(s) \\ \varphi^{(v)}(s) \end{matrix} \right\} = s^{\frac{2v-1}{4}} \left(C_1 \sin \frac{2s^{\frac{3}{2}}}{3\sqrt{3}} + C_2 \cos \frac{2s^{\frac{3}{2}}}{3\sqrt{3}} \right) \cdot \begin{cases} k_v + O\left(s^{-\frac{3}{2}}\right) \\ h_v + O\left(s^{-\frac{3}{2}}\right) \end{cases}, \quad v = 0, 1, 2, \dots, k_v, h_v = \text{const} \neq 0.$$

As $s \rightarrow -\infty$

$$\left. \begin{matrix} f^{(v)}(s) \\ \varphi^{(v)}(s) \end{matrix} \right\} = \begin{cases} O\left(\exp\left(-\frac{|s|^{\frac{3}{2}}}{\sqrt{3}}\right)\right) \\ O\left(\exp\left(-\frac{|s|^{\frac{3}{2}}}{\sqrt{3}}\right)\right) \end{cases}, \quad v = 0, 1, 2, \dots$$

The following relations are true for functions $U(x, y, t; \xi, \eta, \tau)$, $V(x, y, t; \xi, \eta, \tau)$:

$$\begin{aligned} |U(x, y, t; \xi, \eta, \tau)| &< \frac{C}{(t-\tau)^{\frac{2}{3}}} \\ \left| \frac{\partial^i U(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| &\left| \frac{\partial^i V(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| < C_{11} \frac{|x-\xi|^{\frac{2i-1}{4}}}{|t-\tau|^{\frac{6i+5}{12}}}, \quad i = 1, 2, \dots, \\ \left| \frac{\partial^j U(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| &\left| \frac{\partial^j V(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| < C_{12} \frac{|y-\eta|^{\frac{2j-1}{4}}}{|t-\tau|^{\frac{6j+5}{12}}}, \quad j = 1, 2, \dots, \\ \left| \frac{\partial^{i+j} U(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| &\left| \frac{\partial^{i+j} V(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| < C_{13} \frac{|x-\xi|^{\frac{2i-1}{4}} |y-\eta|^{\frac{2j-1}{4}}}{|t-\tau|^{\frac{3i+3j+5}{6}}}, \quad i = 1, 2, \dots, j = 1, 2, \dots \end{aligned} \quad (25)$$

$$\text{as } \frac{x-\xi}{(t-\tau)^{\frac{1}{3}}} \rightarrow +\infty, \frac{y-\eta}{(t-\tau)^{\frac{1}{3}}} \rightarrow +\infty, \quad C_{11} > 0, C_{12} > 0, C_{13} > 0.$$

$$\begin{aligned}
& \left| \frac{\partial^i U(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| \left| \frac{\partial^i V(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| \left\{ < C_{21} \frac{|x - \xi|^{\frac{2i-1}{4}}}{|t - \tau|^{\frac{6i+5}{12}}}, \quad i = 1, 2, \dots, \right. \\
& \left. \left| \frac{\partial^j U(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| \left| \frac{\partial^j V(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| \left\{ < \frac{C_{22}}{|t - \tau|^{\frac{j+2}{3}}} \exp \left(-C_{23} \frac{|y - \eta|^{\frac{3}{2}}}{|t - \tau|^{\frac{1}{2}}} \right), \quad j = 1, 2, \dots \right. \right. \\
& \left. \left| \frac{\partial^{i+j} U(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| \left| \frac{\partial^{i+j} V(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| \left\{ < C_{24} \frac{|x - \xi|^{\frac{2i-1}{4}}}{|t - \tau|^{\frac{6i+4j+13}{6}}} \exp \left(-C_{23} \frac{|y - \eta|^{\frac{3}{2}}}{|t - \tau|^{\frac{1}{2}}} \right), \quad i = 1, 2, \dots, j = 1, 2, \dots \right. \\
& \text{as } \frac{x - \xi}{(t - \tau)^{\frac{1}{3}}} \rightarrow +\infty, \frac{y - \eta}{(t - \tau)^{\frac{1}{3}}} \rightarrow -\infty, \quad C_{21} > 0, C_{22} > 0, C_{23} > 0, C_{24} > 0.
\end{aligned} \tag{26}$$

$$\begin{aligned}
& \left| \frac{\partial^i U(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| \left| \frac{\partial^i V(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| \left\{ < \frac{C_{31}}{|t - \tau|^{\frac{i+2}{3}}} \exp \left(-C_{32} \frac{|x - \xi|^{\frac{3}{2}}}{|t - \tau|^{\frac{1}{2}}} \right), \quad i = 1, 2, \dots, \right. \\
& \left| \frac{\partial^j U(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| \left| \frac{\partial^j V(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| \left\{ < C_{33} \frac{|y - \eta|^{\frac{2j-1}{4}}}{|t - \tau|^{\frac{6j+5}{12}}}, \quad j = 1, 2, \dots \right. \\
& \left| \frac{\partial^{i+j} U(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| \left| \frac{\partial^{i+j} V(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| \left\{ < C_{34} \frac{|y - \eta|^{\frac{2i-1}{4}}}{|t - \tau|^{\frac{6i+4j+13}{6}}} \exp \left(-C_{32} \frac{|x - \xi|^{\frac{3}{2}}}{|t - \tau|^{\frac{1}{2}}} \right), \quad i = 1, 2, \dots, j = 1, 2, \dots \right. \\
& \text{as } \frac{x - \xi}{(t - \tau)^{\frac{1}{3}}} \rightarrow -\infty, \frac{y - \eta}{(t - \tau)^{\frac{1}{3}}} \rightarrow +\infty, \quad C_{31} > 0, C_{32} > 0, C_{33} > 0, C_{34} > 0.
\end{aligned} \tag{27}$$

$$\begin{aligned}
& \left| \frac{\partial^i U(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| \left| \frac{\partial^i V(x, y, t; \xi, \eta, \tau)}{\partial x^i} \right| < \frac{C_{31}}{|t-\tau|^{\frac{i+2}{3}}} \exp \left(-C_{32} \frac{|x-\xi|^{\frac{3}{2}}}{|t-\tau|^{\frac{1}{2}}} \right), \quad i=1,2,\dots, \\
& \left| \frac{\partial^j U(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| \left| \frac{\partial^j V(x, y, t; \xi, \eta, \tau)}{\partial y^j} \right| < \frac{C_{22}}{|t-\tau|^{\frac{j+2}{3}}} \exp \left(-C_{23} \frac{|y-\eta|^{\frac{3}{2}}}{|t-\tau|^{\frac{1}{2}}} \right), \quad j=1,2,\dots \\
& \left| \frac{\partial^{i+j} U(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| \left| \frac{\partial^{i+j} V(x, y, t; \xi, \eta, \tau)}{\partial x^i \partial y^j} \right| < \frac{C_4}{|t-\tau|^{\frac{i+j+2}{3}}} \exp \left(-C_{32} \frac{|x-\xi|^{\frac{3}{2}}}{|t-\tau|^{\frac{1}{2}}} - C_{23} \frac{|y-\eta|^{\frac{3}{2}}}{|t-\tau|^{\frac{1}{2}}} \right), \quad i=1,2,\dots, j=1,2,\dots \quad (28)
\end{aligned}$$

as $\frac{x-\xi}{(t-\tau)^{\frac{1}{3}}} \rightarrow -\infty, \frac{y-\eta}{(t-\tau)^{\frac{1}{3}}} \rightarrow -\infty$, $C_4 > 0$.

Solution to problem (16), (19) is sought in the following form:

$$\begin{aligned}
W(x, y, t; \xi, \eta, \tau) = & \int_{\tau}^t \int_0^1 U_{\xi}(1, y, s; \xi, \eta, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_{\tau}^t \int_0^1 V_{\xi}(1, y, s; \xi, \eta, \tau) \alpha_2(x, y, s) d\eta ds + \int_{\tau}^t \int_0^1 U_{\xi\xi}(0, y, s; \xi, \eta, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_{\tau}^t \int_0^1 U_{\eta}(x, 1, s; \xi, \eta, \tau) \beta_1(x, y, s) d\xi ds + \\
& + \int_{\tau}^t \int_0^1 V_{\eta}(x, 1, s; \xi, \eta, \tau) \beta_2(x, y, s) d\xi ds + \int_{\tau}^t \int_0^1 U_{\eta\eta}(x, 0, s; \xi, \eta, \tau) \beta_3(x, y, s) d\xi ds. \quad (29)
\end{aligned}$$

Obviously, function $W(x, y, t; \xi, \eta, \tau)$ satisfies condition $W(x, y, t; \xi, \eta, \tau)|_{\tau=t} = 0$.

Satisfying the boundary conditions (19) we obtain

$$\begin{aligned}
U(x, y, t; 0, \eta, \tau) = & \int_{\tau}^t \int_0^1 U_{\xi}(1, y, s; 0, \eta, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_{\tau}^t \int_0^1 V_{\xi}(1, y, s; 0, \eta, \tau) \alpha_2(x, y, s) d\eta ds + \int_{\tau}^t \int_0^1 U_{\xi\xi}(0, y, s; \xi, \eta, \tau) \Big|_{\xi=0} \alpha_3(x, y, s) d\eta ds + \\
& + \int_{\tau}^t \int_0^1 U_{\eta}(x, 1, s; 0, \eta, \tau) \beta_1(x, y, s) d\xi ds + \int_{\tau}^t \int_0^1 V_{\eta}(x, 1, s; 0, \eta, \tau) \beta_2(x, y, s) d\xi ds + \\
& + \int_{\tau}^t \int_0^1 U_{\eta\eta}(x, 0, s; 0, \eta, \tau) \beta_3(x, y, s) d\xi ds = I_{11} + I_{12} + I_{13} + I_{14} + I_{15} + I_{16}. \quad (30)
\end{aligned}$$

$$\begin{aligned}
U(x, y, t; 1, \eta, \tau) = & \int_0^t \int_0^1 U_{\xi}(1, y, s; 1, \eta, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 V_{\xi}(1, y, s; 1, \eta, \tau) \alpha_2(x, y, s) d\eta ds + \int_0^t \int_0^1 U_{\xi\xi}(0, y, s; 1, \eta, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\eta}(x, 1, s; 1, \eta, \tau) \beta_1(x, y, s) d\xi ds + \\
& + \int_0^t \int_0^1 V_{\eta}(x, 1, s; 1, \eta, \tau) \beta_2(x, y, s) d\xi ds + \int_0^t \int_0^1 U_{\eta\eta}(x, 0, s; 1, \eta, \tau) \beta_3(x, y, s) d\xi ds.
\end{aligned} \tag{31}$$

$$\begin{aligned}
U_{\xi}(x, y, t; 1, \eta, \tau) = & \int_0^t \int_0^1 U_{\xi\xi}(1, y, s; \xi, \eta, \tau) \Big|_{\xi=1} \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 V_{\xi\xi}(1, y, s; 1, \eta, \tau) \Big|_{\xi=1} \alpha_2(x, y, s) d\eta ds + \int_0^t \int_0^1 U_{\xi\xi\xi}(0, y, s; 1, \eta, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\eta\xi}(x, 1, s; 1, \eta, \tau) \beta_1(x, y, s) d\xi ds + \int_0^t \int_0^1 V_{\eta\xi}(x, 1, s; 1, \eta, \tau) \beta_2(x, y, s) d\xi ds + \\
& + \int_0^t \int_0^1 U_{\eta\eta\xi}(x, 0, s; 1, \eta, \tau) \beta_3(x, y, s) d\xi ds = I_{31} + I_{32} + I_{33} + I_{34} + I_{35} + I_{36}.
\end{aligned} \tag{32}$$

$$\begin{aligned}
U(x, y, t; \xi, 0, \tau) = & \int_0^t \int_0^1 U_{\xi}(1, y, s; \xi, 0, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 V_{\xi}(1, y, s; \xi, 0, \tau) \alpha_2(x, y, s) d\eta ds + \int_0^t \int_0^1 U_{\xi\xi}(0, y, s; \xi, 0, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\eta}(x, 1, s; \xi, 0, \tau) \beta_1(x, y, s) d\xi ds + \int_0^t \int_0^1 V_{\eta}(x, 1, s; \xi, 0, \tau) \beta_2(x, y, s) d\xi ds + \\
& + \int_0^t \int_0^1 U_{\eta\eta}(x, 0, s; \xi, \eta, \tau) \Big|_{\eta=0} \beta_3(x, y, s) d\xi ds = I_{41} + I_{42} + I_{43} + I_{44} + I_{45} + I_{46}.
\end{aligned} \tag{33}$$

$$\begin{aligned}
U(x, y, t; \xi, 1, \tau) = & \int_0^t \int_0^1 U_{\xi}(1, y, s; \xi, 1, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 V_{\xi}(1, y, s; \xi, 1, \tau) \alpha_2(x, y, s) d\eta ds + \int_0^t \int_0^1 U_{\xi\xi}(0, y, s; \xi, 1, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\eta}(x, 1, s; \xi, 1, \tau) \beta_1(x, y, s) d\xi ds + \\
& + \int_0^t \int_0^1 V_{\eta}(x, 1, s; \xi, 1, \tau) \beta_2(x, y, s) d\xi ds + \int_0^t \int_0^1 U_{\eta\eta}(x, 0, s; \xi, 1, \tau) \beta_3(x, y, s) d\xi ds.
\end{aligned} \tag{34}$$

$$\begin{aligned}
U_{\eta}(x, y, t; \xi, 1, \tau) = & \int_0^t \int_0^1 U_{\xi\eta}(1, y, s; \xi, 1, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 V_{\xi\eta}(1, y, s; \xi, 1, \tau) \alpha_2(x, y, s) d\eta ds + \int_0^t \int_0^1 U_{\xi\xi\eta}(0, y, s; \xi, 1, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\eta\eta}(x, 1, s; \xi, \eta, \tau) \Big|_{\eta=1} \beta_1(x, y, s) d\xi ds + \int_0^t \int_0^1 V_{\eta\eta}(x, 1, s; \xi, \eta, \tau) \Big|_{\eta=1} \beta_2(x, y, s) d\xi ds + \\
& + \int_0^t \int_0^1 U_{\eta\eta\eta}(x, 0, s; \xi, 1, \tau) \beta_3(x, y, s) d\xi ds.
\end{aligned} \tag{35}$$

Multiplying both sides of equations (31) by $(z - \tau)^{-\frac{1}{3}}$, (z – parametr),

we integrate them between y and z . Then, differentiating with respect to z , after simple transformations, we obtain the following system of integral equations:

$$\begin{aligned}
U(x, y, t; 0, \eta, \tau) = & \int_0^t \int_0^1 U_{\xi}(1, y, s; 0, \eta, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 V_{\xi}(1, y, s; 0, \eta, \tau) \alpha_2(x, y, s) d\eta ds + \frac{\pi\mu_1}{3} \alpha_3(x, y, \tau) \\
& + \int_0^t \int_0^1 U_{\eta}(x, 1, s; 0, \eta, \tau) \beta_1(x, y, s) d\xi ds + \int_0^t \int_0^1 V_{\eta}(x, 1, s; 0, \eta, \tau) \beta_2(x, y, s) d\xi ds + \\
& + \int_0^t \int_0^1 U_{\eta\eta}(x, 0, s; 0, \eta, \tau) \beta_3(x, y, s) d\xi ds,
\end{aligned} \tag{36}$$

$$\begin{aligned}
\frac{d}{dz} \int_t^z (z - \tau)^{-\frac{1}{3}} U(x, y, t; 1, \eta, \tau) d\tau = & B\left(\frac{2}{3}; \frac{1}{3}\right) f'(0) \mu_1 \alpha_1(x, y, z) + B\left(\frac{2}{3}; \frac{1}{3}\right) \phi'(0) \mu_2 \alpha_2(x, y, z) + \\
& + \frac{\partial}{\partial z} \int_t^z \alpha_3(x, y, s) \left[\int_s^1 (z - \tau)^{-\frac{1}{3}} U_{\xi\xi}(0, y, s; 1, \eta, \tau) d\eta d\tau \right] ds + \\
& + \frac{\partial}{\partial z} \int_t^z \beta_1(x, y, s) \left[\int_s^1 (z - \tau)^{-\frac{1}{3}} U_{\eta}(x, 1, s; 1, \eta, \tau) d\xi d\tau \right] ds + \\
& + \frac{\partial}{\partial z} \int_t^z \beta_3(x, y, s) \left[\int_s^1 (z - \tau)^{-\frac{1}{3}} U_{\eta\eta}(x, 0, s; 1, \eta, \tau) d\xi d\tau \right] ds,
\end{aligned} \tag{37}$$

$$\begin{aligned}
U_{\xi}(x, y, t; 1, \eta, \tau) = & \frac{2\pi}{3} \mu_1 \alpha_1(x, y, \tau) + \int_0^t \int_0^1 U_{\xi\xi\xi}(0, y, s; 1, \eta, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\eta\xi}(x, 1, s; 1, \eta, \tau) \beta_1(x, y, s) d\xi ds + \int_0^t \int_0^1 U_{\eta\eta\xi}(x, 0, s; 1, \eta, \tau) \beta_3(x, y, s) d\xi ds,
\end{aligned} \tag{38}$$

$$\begin{aligned}
U(x, y, t; \xi, 0, \tau) = & \int_0^t \int_0^1 U_{\xi}(1, y, s; \xi, 0, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 V_{\xi}(1, y, s; \xi, 0, \tau) \alpha_2(x, y, s) d\eta ds + \int_0^t \int_0^1 U_{\xi\xi}(0, y, s; \xi, 0, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\eta}(x, 1, s; \xi, 0, \tau) \beta_1(x, y, s) d\xi ds + \int_0^t \int_0^1 V_{\eta}(x, 1, s; \xi, 0, \tau) \beta_2(x, y, s) d\xi ds + \\
& + \frac{2\pi}{3} \mu_2 \beta_3(x, y, \tau),
\end{aligned} \tag{39}$$

$$\begin{aligned}
\frac{d}{dz} \int_t^z (z-\tau)^{-\frac{1}{3}} U(x, y, t; \xi, 1, \tau) d\tau = & \frac{\partial}{\partial z} \int_t^z \alpha_1(x, y, s) \left[\int_s^z \int_0^1 (z-\tau)^{-\frac{1}{3}} U_{\xi}(1, y, s; \xi, 1, \tau) d\eta d\tau \right] ds + \\
& + \frac{\partial}{\partial z} \int_t^z \alpha_3(x, y, s) \left[\int_s^z \int_0^1 (z-\tau)^{-\frac{1}{3}} U_{\xi}(0, y, s; \xi, 1, \tau) d\eta d\tau \right] ds + \\
& + \frac{\partial}{\partial z} \int_t^z \beta_1(x, y, s) \left[\int_s^z \int_0^1 (z-\tau)^{-\frac{1}{3}} U_{\eta}(x, 1, s; \xi, 1, \tau) d\xi d\tau \right] ds + \\
& + B\left(\frac{2}{3}; \frac{1}{3}\right) \phi'(0) \mu_3 \beta_2(x, y, \tau) + \frac{\partial}{\partial z} \int_t^z \beta_3(x, y, s) \left[\int_s^z \int_0^1 (z-\tau)^{-\frac{1}{3}} U_{\eta\eta}(x, 0, s; \xi, 1, \tau) d\xi d\tau \right] ds,
\end{aligned} \tag{40}$$

$$\begin{aligned}
U_{\eta}(x, y, t; \xi, 1, \tau) = & \int_0^t \int_0^1 U_{\xi\eta}(1, y, s; \xi, 1, \tau) \alpha_1(x, y, s) d\eta ds + \\
& + \int_0^t \int_0^1 U_{\xi\xi\eta}(0, y, s; \xi, 1, \tau) \alpha_3(x, y, s) d\eta ds + \\
& + \frac{2\pi}{3} \mu_2 \beta_1(x, y, \tau) + \int_0^t \int_0^1 U_{\eta\eta\eta}(x, 0, s; \xi, 1, \tau) \beta_3(x, y, s) d\xi ds.
\end{aligned} \tag{41}$$

The system (36) - (41) is a system of Volterra integral equations for unknown functions $\alpha_k(x, y, \tau)$, $\beta_k(x, y, \tau)$ ($k=1,2,3$).

If $\alpha_k(x, y, z) \in C(D)$, $k=1,2,3$, $\beta_1(x, y, z) \in C(D)$, $\beta_2(x, y, z) \in C(D)$, $\beta_3(x, y, z) \in C^1(D)$, then the system (36)-(41) is solvable.

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MOLECULAR PHYSIOLOGY AND GENETICS

PROSTHETICS WITH ALL-CERAMIC RESTORATIONS IN THE ORAL CAVITY

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Abstract

All-ceramic fixed prostheses represent a specialized area of prosthodontics. Veneers are often required to restore the anterior teeth. However, when the thickness of the ceramic veneer increases, there is a higher risk of chipping and an increased likelihood of pulpitis following tooth preparation. In such cases, it is recommended to perform endodontic treatment, restore the teeth with zirconia post-and-core restorations, and fabricate zirconia crowns with ceramic veneering.

Keywords: veneers; ceramic veneering; tooth preparation.

All-Ceramic Fixed Prostheses in Prosthodontics

All-ceramic fixed prostheses represent a specialized branch of prosthodontics; veneers are necessary for the restoration of anterior teeth. Key factors in planning the prosthetic restoration of a tooth include its topography and anatomical features (position, anatomical shape). It is important to consider the size of the hard tissue defect, the ratio of pulp to hard dental tissues (dentin, enamel), the type of occlusion, the direction of forces acting on the prosthetic restoration, the inclination of the tooth, and the results of radiographic examination.

Objective: To investigate the principles of tooth preparation and the features of forming a natural anatomical contour in all-ceramic restorations.

MATERIALS AND METHODS

To determine the color-optical characteristics of future prostheses, it is convenient to use the **Vitapan 3-D Master Shade Guide**, which characterizes the volume, saturation, and hue of the color. The first step is to determine the color of the canines (the most saturated color). The red scale is used to determine the dentin shade (initial scale), while the blue scale is used for the cervical and central areas of the incisors [1].

Indications for veneers:

- Tooth discoloration (fluorosis, defective fillings)
- Anatomical defects of teeth (chipping of the crown)
- Developmental anomalies of teeth (hypoplasia, imperfect amelogenesis)
- Abnormal tooth positioning (alternative to orthodontic treatment)

For achieving high-quality results with all-ceramic fixed prostheses, the following aesthetic criteria must be considered:

- Tooth shape
- Tooth position (axis inclination)
- Interdental space and level of contacts
- Gingival biotype
- Gingival color and gingival margin position
- Zenit of the gingival contour
- Tooth color (shades)
- Incisal edge level of anterior teeth
- Tooth surface relief
- Smile line and lower lip position [2]

Rules for veneer fabrication:

- Preparation should be limited to the enamel layer
- Veneers should be made only on vital teeth
- Whenever possible, preserve natural tooth boundaries (partial preservation of contact points if aesthetically feasible)

Contraindications for ceramic prostheses:

- Significant tooth malposition (lingual or palatal)
 - Major loss of hard tissues (>1/3 of crown)
 - Excessive tooth wear
 - Unrestored dental defects (incomplete prosthodontic treatment)
 - Deep bite
 - Parafunctional habits of masticatory muscles
- Before veneer fabrication, it is necessary to:
- Perform radiographic examination of the teeth to be restored
 - Assess oral hygiene and perform professional cleaning if needed

- Determine the final color of the restoration (with written patient consent)
- Replace all defective fillings
- Fabricate diagnostic models
- Optionally perform wax-up modeling on a cast or intraoral mock-up with fast-setting resin

- Take radiographs to evaluate pulp chamber location and enamel thickness

- Detect carious lesions

- Evaluate interdental spaces and contact points

Tooth preparation features for veneers:

- Cervical margin corresponds to the gingival margin

- Preparation margin is positioned 1 mm above the gingiva; in case of severe discoloration, the margin may be 0.5 mm below the gingiva

Preparation stages:

1. **Calibrating bur (round):** determine preparation depth depending on tooth size (cervical part 0.3 mm, equator 0.5 mm, incisal edge 0.8 mm) with water cooling

2. Create boundaries of the future veneer using the round bur

3. Prepare contact surfaces partially, preserving natural tooth contact points

4. Cervical area preparation: depth not more than 0.3 mm [1–4]

5. **Torpedo-shaped bur:** smooth incisions and thin vestibular surface; connect boundaries with fissure burs of corresponding diameter, starting with vertical aspects (proximal grooves – deeper on mesial, thinner on distal)

6. Final surface polishing using burs (red, yellow, white coding) and rubber polishing heads

This protocol ensures precise preparation and optimal aesthetics for all-ceramic veneers.

RESULTS

During tooth preparation, it is essential to preserve the **vestibular surface relief** of the tooth, repeating its natural anatomical shape. The **veneer thickness** should be uniform: different anatomical areas require removal of varying amounts of hard tissue (especially if the tooth is malpositioned), which can be guided using a **silicone key**. Contact with the opposing tooth's surface (incisal edge) should **not occur on the veneer surface or margin**, but only on natural tooth tissue [3–5].

Preference should be given to **palatal (lingual) preparation** with partial or complete coverage — contact with the veneer is preferable to contact at the enamel junction. Small mandibular incisors have limited retention, so the preparation margin should extend to the **upper third of the palatal (lingual) surface**; otherwise, there is a risk of chipping or marginal misfit.

The thickness at the incisal edge should not exceed **1 mm** [5, 6].

Veneers are usually cemented using **light-curing composite materials**. Excess material should preferably be removed with a **polishing bur**, not a probe, because probing may create **microgaps** between the cement, veneer margin, and tooth surface. Such gaps can lead to **plaque accumulation, decementation, and secondary caries** in the affected area.

Conclusions

In cases of significant diastemas (gaps between the central incisors) and when the patient refuses orthodontic treatment, creating **contact points on veneers** is a challenging clinical task, often resulting in a “spade-shaped” crown.

Additionally, if more than **one-third of the crown structure** is lost (moderate to severe wear, grades 2–3), using veneers becomes **risky** due to the increased thickness of the ceramic layer. This increases the likelihood of **veneer chipping** and the risk of **pulpitis** after tooth preparation.

Under such conditions, it is **preferable to perform endodontic treatment**, restore the tooth with **zirconia post-and-core structures**, and fabricate **zirconia crowns with ceramic veneering** for optimal durability and esthetics.

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PEDAGOGY

ТӨКМӨНҮН ЫРЛАРЫНЫН МАЗМУНУНУН КУРЧТУГУ, КӨРКӨМДҮГҮ ЖАНА ЧЫНЧЫЛДЫГЫ ЖАШ МУУНДУ АДЕП-АХЛАКТЫК ТАРБИЯЛООНУН ТААСИРДҮҮ КАРАЖАТЫ КАТАРЫ (ТУЯК ЫРЧЫНЫН ТӨКМӨЛҮК ӨНӨРҮНҮН МИСАЛЫНДА)

Бердыбаев А.К.,
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THE SHARPNESS, ARTISTRY AND TRUTHFULNESS OF THE CONTENT OF THE IMPROVISATIONAL POET'S POEMS AS AN EFFECTIVE MEANS OF MORAL EDUCATION OF THE YOUNGER GENERATION (USING THE EXAMPLE OF POEMS OF TUYAK YRCHY)

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Аннотация

Сунушталган илимий макалада XIX кылымда Кыргызстандын түштүк-батыш чөлкөмүндө төрөлгөн жана жашаган Туяк ырчынын төкмөлүк өнөрүнүн кандайлыгын анын ыр саптарын аңдоо аркылуу баамдоо мүмкүн. Ошондой эле ырчынын инсандык сапатынын жогорулугу, Туяктын ою боюнча, төкмөнүн курчтугу, чынчылдыгы, адилеттүүлүгү, эл-журттон кызыкчылыгын, таламын көздөгөндүгү, коргогондугу саналат. Андай төкмөлөрдү жалпы эл кадырлап, барктап, алардын өнөр кудуретин, көркөм мурасын, дараметин муундан муунга даңазалайт.

Туяк ыр саптарында айрым төкмөлөр байлардын, манаптардын аш-той, мааракелерде аларга кошоматтанып, жагалданып аларды алкап, даңктап ырдаганын сынга алат. Мына ушундай татыксыз аракети менен өзүлөрүнүн адамдык абийирине, ырчылык өнөрүнө көлөкө түшкөнүн алардын өзүлөрү да аңдап-туйбай калышарын текстте мүнөздөйт.

Abstract

In this scientific article, based on the analysis of the poems of Tuyak yrchy, who was born, lived and worked in the 19th century in the southwestern region of Kyrgyzstan, we can draw a definite conclusion about his improvisational talent.

According to Tuyak, if an improvisational poet is honest and fair, when his poems address acute, pressing issues of life and everyday life, and his poems reflect the interests of the people, then such a poet should be characterized as a person worthy of respect and high honour.

The names of such improvisational poets are sacredly preserved in the memory and in the hearts of the people, their artistic heritage is passed down from generation to generation, voiced by word of mouth.

In his poems, Tuyak exposes some criticism of the unworthy behaviour of some improvisational poets who were engaged in sycophancy, praising bais (*bai* – (archaism) - (from Turkish *bay* - (tribal) chief, leader) - a big landowner, a wealthy cattle owner) and manaps (manap (archaism) - a representative of the privileged feudal estate of the northern Kyrgyz - (tribal) chief, leader) in their own celebrations.

By such actions, they cast a shadow on their human dignity, subjecting themselves to humiliation, sometimes without even noticing it.

Негизги сөздөр: курчтугу, көркөмдүгү, чынчылдыгы, төкмө, адеп-ахлак тарбиясы, төкмөлүк талант, урматтоо, жогору кадыр-барк, чыгармачылык мурас, татыксыз жүрүм-турум, кошоматтануу.

Keywords: sharpness, artistry, truthfulness, poet-improviser, moral education, improvisational talent, worthy respect, high honour, creative heritage, unworthy behaviour, sycophancy.

Киришүү. Адам баласы жаралгандан тарта уруу-урук, жамаат, андан соң коомдошуп жашоосунда алардын биригүүсүнө, баш кошуусуна түрткү болгон негизги фактор – таалим-тарбия мыйзамдары, принциптери, эрежелери жана элдик акыл-насааттар боло келген.

Андыктан ата-бабалардын рухий көрөңгөсүнө, алардын алгылыктуу социалдык тажрыйбасына сереп салуунун зарылдыгы барган сайын көзгө уруна баштады. Мындан улам соңку кезде педагогика илиминин олуттуу тармагынын бири болуп эсептелген этнопедагогиканын идеялары синтезделип жаткандыгы жагымдуу жана объективдүү көрүнүш.

Кыргыз акындары тарабынан иштелип чыккан таалим-тарбиялык ойлор муундан муунга

өткөрүлүп жана эл турмушунда апробацияланып, жаштардын руханий өнүгүүсүнүн таасирдүү факторуна айланган. Профессор А. Т. Калдыбаева: "... акындар – кыргыз коомунда прогрессивдүү идеяларды алып жүрүүчүлөр, элдик наркты таратуучулар, калкты жакшы жакка үгүттөөчүлөр, оң жана терс көрүнүштөргө карата эстетикалык идеалды, табитти жаратуучулар, акыры жалпы калктын бала бакчасы, мектеби, университети болгон", - деп таасын белгилейт [9, 5-6.].

Изилдөөнүн методдору: коюлган теманын алкагында тиешелүү мазмунду ылгоо, окуп-үйрөнүү, талдоо, синтез, индукция, дедукция, абстракция, салыштыруу, конкреттештирүү, жалпылоо, тексти интерпретациялоо жана башка илимий таануу методдору колдонулду.

Негизги мазмун. Чыныгы, нукура ырчылар эл алдында сүрдөбөйт, табият белендеген аземдүү конур үнү, ал абазы жүрөгүнөн толкуп чыккан жылаажын сындуу күүгө ээ болуп, абдан жарылып, илхам менен ырдаганы үчүн калың элдин назарына илинип, купулуна толуп, ырынды “кирген суудай ташып айт”, - деп:

Анык ырчы ар дайым

Жүрөгүнө бир бүдүр

Сырды катып жашырбайт, - делет [1, 22-б.].

Бүдүр – 1. Майда – майда бүртүк. Эч нерсени катпайт, жашырбайт деген мааниде.

Жылаажындай Өтө мукам, назик, жылаажындын үнүндөй, уккулуктуу (үнгө карата) [2, 511-б.].

Оомат Байлык, бакыт, бийлик [2, 994-б].

Маселен, эпостогу эң алгачкы манасчы атыккан Ырамандын Ырчы уулу тууралуу, - таанымал илимпоз Советбек Байгазиев, - Манастын баатырдыгы жана Каныкейдин ханга жароокер жар экендиги жөнүндө ырдаганын көргөнүн көргөндөй ал ырга салган болуу керек, мындай айтканда документалдуу анык маалымат катары кабылдоого болот”, - дейт [8].

Төмөндөгү саптарда акындын төккөн ырлары ага бакыт белендээри, кут, ырыскы болору тууралуу ой-нуска айтылат:

Ооматы келсе ырчынын

Таңдайынан от чыгат.

Сөздөрүнүн ичинен

Алоолонгон от чыгат.

Бирде күлүп каткырат,

Аба жетпей аптыгат.

Нөшөр болуп төгүлөт,

Нурдай болуп көрүнөт.

Куюлушуп сөздөрү,

Кумардуу карайт көздөрү [1, 22-б.].

Андан ары акын ооматы качкан ырчынын кабылган жагдайын абдан таасын мүнөздөйт, башкача айтканда сөзүнүн кунары качарын, дымагы өчөөрүн, ошого карабай өзүн өйдө сезип, тоотпос пейил күткөнүн, сөзүндө кайталоочулук орун алып (тантып), элдин тажаганын өзү да андабай каларын, бирок аш-тойго барууну ар дайым самап турат деген ойду берет. Бул ой тыянагы аркылуу Туяк сындуу ырчылар эл ичиндеги өзүлөрүнүн кадыр-баркынын, урмат-сыйынын канчалык даражада экенин ар дайым сезимтал, сергек баалап, акыл таразасына салып, өзүнө сын көз менен кароонун маанилүүлүгүн белгилейт.

Жакшы ой, ниет менен кол кармашып жашайын деп тилек кылган, сүйүп алган “Эр азамат кар болбойт”, - дейт. Жакшы жана жаманды айырмалай билсе, андай жигиттин акыл өрүшү кенен болорун айтып:

Өсө турган эр жигит

Ар убак намыс, арды ойлойт – деген саптар аркылуу канааттануу, ыраазы болуу сезимин билдирет [1, 24-б.]. Андай жигиттин никелеп алган катыны акыл-эстүү жан болот, - деп, ар дайым кабак-кашым дебей, ачык-айрым, шайдоот мүнөз күтүп, айрым учурда үйдө боло калчу начар, терс

көрүнүштөрдү сыртка алып чыкпай, сыр катканын акын жогору баалайт.

Болбой турган, башкача айтканда пас жигиттин үйүндө аялы бийлээрин, очогунун айланасында дайыма жуулбаган идиш-аяктын үйүлүп турарын, андай аял айылчылап жүрүүнү сүйөрүн, көңүл дитин коюу менен тамак жасабасын, сөзүн да чала сүйлөп, жасаган тамагы сынары тузсуз болорун, болор-болбос нерсе үчүн күйөөсүнө таарынып турарын, үйүнө мейман келсе:

Карыш бүркөйт кабагын.

Көрүп алгын ошондо

Көздөрүнүн чанагын, - делет [1, 25-б.].

Кабагын бүркөө сабыры суз, түнөрүңкү абалда болуу. Капа болгондой, же бир нерсени жактырбагандай көрүнүш [2, 580-б.].

Көзү чанагынан чыгуу Катуу корккондо, таң калганда же ачуусу келгенде көзү чоң ачылып бакырая түшүп, акырая кароо [2, 567-б.].

Калыгул “Жакшы катын” жана “Жаман катынды” салыштырып:

Жакшы болсо катының,

Табыла берет акылың,

Куусаң да кетпейт жакының.

Жаман болсо катының,

Кете берет акылың,

Чакырсаң келбейт жакының - делет [5, 32-б.].

Профессор Абдыкерим Муратов “Молдо Нияз - алгачкы агартуучу” - аталышындагы китебинде эки түрдүү катындын, башкача айтканда “жакшы катын, жаман катын” көркөм каражаттар аркылуу образын айкыныраак ачуу жаатында таблица колдонууну максатка ылайык көрөт жана аларды: 1. Мүнөз-пейили боюнча; 2. Кылган иши боюнча; 3. Келбети, өңү түсү боюнча салыштырат [7, 107-109-бб.]. Алсак, **Мүнөз-пейилине жараша:**

Жакшы катын

Жаман аял пейли жок,

Арам ишке майли жок.

Жаман айтпайт эриге,

Жакшы болот элиге.

Жаман катын

Эчтеме менен иши жок,

Эч сүйлөбөйт корсоюп.

Кылган ишине карата:

Жакшы катын

Эсеп менен пул кылат,

Эшик тышын жол кылат.

Кайриеттүү иш кылат.

Уул, кызын урматтап,

Кийгенин кымкап, киш кылат,

Дүнүйөсү көп болсо,

Итаягын мис кылат.

Жаман катын

Жакшы эрини кул кылат.

Аш кылса, ичин кыл кылат,

Ак үйүнү жол кылат,

Алган эрин сил кылат.

Айтса гапти албастан,

Адамды бир пул кылат.

Арам, адал иш кылып,

Жакшы көңүл кир кылат.

Айрым сөздөргө түшүндүрмө: **Гап** - сөз [6, 170-б.],

Сил - оору [6, 172-б.].

Өсө турган жигиттин сөзүндө маани, көзүндө нур болорун, жүрөгү жакшылык жасоого согуп турарын, улуу-кичүүгө маанилүү кеңеш, насаат айтаарын баяндайт. Ошондой азаматты эл ичинде жакшы өмүр сүрүүгө, жакшы ат менен элдин эсинде калууга, дүнүйө, мансап артынан түшүп кубалабоого санаттап:

Дүйнө деген ташканак.

Ач көз кылып акыры

Акылыңды башкарат.

Унутасың уйкуну,

Анык азап башталат, - дейт [1, 25-б.].

“**Ташканак**” деген сөздүн түшүндүрмөсүн сөздүктөрдөн табалбадык. Биздин баамыбызда, акындын ыр саптарынын таризинде аңдасак, **ташканак** – бул дүнүйөнүн артынан сая түшүү ачкөздүккө, сараңдыкка алып келип, адамдын рухий жан дүйнөсүн тайыздатып, айнытып, ал түгүл адамдык жүздөн ажыратып, аягы жакшылык менен бүтпөсүн нускалайт.

Баш мээң да айныгансып, акылыңды токтото албай калган абалга тушугасың деп, ач көз сараңдыгың чек билбей:

Мал туягың көбөйтүп

Маарып кетем дебегин.

Маргалаңдын базарын

Алып кетем дебегин.

Кызыл кымкап матага

Тунуп калам дебегин.

Түркүк болуп дүйнөгө

Туруп калам дебегин, - деген таасын мүнөздөмөсүн айтат, мындайча айтканда ашыкча дүнүйө адамдык нарк-насилге кедергисин тийгизээрин белгилейт.

Сатыбалды Сайпидин уулу жарыялаган “Молдо Нияз – жазгыч акын” деген макаласында: “Молдо Нияз ...өзү жашаган доордогу эзүүгө, теңсиздикке адилет баа берген. Ал өзүнүн ырларында адамдарды салыштырып да ырдаган:

“Тамашада Ак эшен

Саакыда мындай көрбөдүм.

Шаймарданда Мамажан

Бакылдан мындай көрбөдүм”.

Мында, **бакыл** – карик, башка бирөөнүн жакшылыгын же жетишкендигин көрө албаган, өчөшкөөк, бирөөнүн жакшы ишине тескери (жаман) иш жасоо менен жооп берүү [10, 128-б.].

Бакыл Сараң, ичи тар, дүйнөкор кунарсyz. Баладан малды жуук көргөн, Бакыл киши экенсиң (“Манас”) [10, 165-б.].

Бул ырында Ак эшен Тамаша айылында туруп, кедей-кембагалдарга жардам берип, жетим-жесирлерди баккан. Ал балдарды окуткан. Ал эми Мамажан болсо Шаймардандик бай болгон. Ал элди ырайымсыздык менен эзип иштеткен. Ошондуктан эл аны жек көргөн”, - деп сыпаттайт [11].

Бардык топтогон байлыгың бул дүйнөдө калат, аны өзүң менен кошо мүрзөңө алып кетпейсиң, “Малың калат маараган”, “Доорон сүргөн

тамыңдын, Орду бүгүн селкана ...” [1, 26-б.], башкача айтканда мезгил өтүп ошол тамынын урандыга айланып, түз болорун, чиренген дүнүйөсүнүн төмөндөгү саптарда чачылып-чарпылары жөнүндө эскерткени баамдалат:

Сары өтөккө жык толгон

Койлоруңдан дайын жок.

Дүйнө деген ушундай,

Учат колго тутулбай [1, 26-б.].

Акындын негизги ой-пикирин жайыттарда (жайлоолордун аталышын атап) жайылган койлоруң, кокту-колотторго жык толгон жылкыларың канаке? - деп, маркумга собол узатуу менен окурманды дүнүйө, байлык, акыр түбү тууралуу ойлонууга, акыл калчоого жем таштап жатат десек болот. Андан ары акын иш-аракет жасоого, эмгектенүүгө үндөйт. Аракетиң болсо үй-жай, там саласың, эгер жалакай, жалкоо болсон, курсагың нанга, ашка тойбойт, “Арыгыңа суу келбейт”, мындайча айтканда “Суу – өмүр азыгы” дегендей арыгыңда суунун агышы да эмгек аркылуу болорун белгилейт; жакшы жагың менен эл оозуна алынбай, калк назарына илинбей, аты-затыңды эл атабай, тескерисинче, эл арасында пас саналган пенденин предметине айланышын айтып, төмөнкү саптар аркылуу ойлорун дагы дааналайт:

Мөмөлөбөйт бактарың,

Көбөйбөйт жыйнап тапканың.

Ийиң жылбайт алдыга,

Чачылып жатат тааштарың,

Жыйылбайт эккен эгиниң,

Жыйымдуу чыкпайт келиниң [1, 27-б.].

Андыктан аракетин болбосо, эч нерсеге жетишпей, зарыл нерсеге муктаж, “Кийериңе кийим жок” болуп, чүнчүп жүрүп:

Өзүңдөн өзүң өчөсүң

Бары-жогоң билинбей,

Оо дүйнөгө көчөсүң [1, 27-б.]. Ошондуктан акын санаттарын ишмердикке, мээнет кылууга чакырган төмөндөгү саптар менен оюн жыйынтыктайт:

Жаш кезиңден жигиттер

Бекерликке берилбе.

Аракетиң кылып ал

Күн өтпөсүн бекерге.

Белиңде күчүң барында,

Оокаттын болуп камында

Күнү-түнү иштегин,

Өзү келет табылга ... [1, 27-б.].

Жогорудагылардын негизинде төмөнкүдөй жыйынтыкка келүү мүмкүн.

Корутунду: Туяк өзүнүн ыр саптарында төкмөлүк өнөрдүн күчү, таасири, салмагы эмнеде экендигин, төкмө ырчынын эл ичиндеги абройго, кадыр-баркка ээ болушунун ченемдерин сыпаттайт; анын ырларында камтылган мазмунду аңдап-туюу аркылуу Туяктын өзүнүн туулуп өскөн эл-жеринин эртеңин ойлогон, келечек тагдыры үчүн түйшөлгөн мекенчилдик сезимдерин аңдоого мүмкүн; Туяктын ыр саптарынын мазмунун аңдасак, анын төкмөлүк өнөрдүн мыкты салттарын алып жүрөрүн жана ага сугарылгандыгы байкалат.

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ПОДГОТОВКА БУДУЩИХ УЧИТЕЛЕЙ К ИНТЕГРИРОВАННОМУ ОБУЧЕНИЮ ДЕТЕЙ В НАЧАЛЬНОЙ ШКОЛЕ**Усенова Н.Э.**

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TRAINING FUTURE TEACHERS FOR INTEGRATED EDUCATION OF CHILDREN IN PRIMARY SCHOOL**Usenova N.**

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Аннотация

Данная научная статья исследует проблемы интеграции в образовательном процессе детей начальной школы. Так как в педагогической системе каждой эпохи возникают определенные преобразования, требующие уделения внимания детям как будущим строителям социальной культуры. Целью работы является с точки зрения педагогической науки обосновать необходимость подготовки будущих учителей к интегрированному обучению детей в образовательной деятельности начальных школ Кыргызстана. При подготовке будущих учителей к обучению детей в начальной школе рекомендуется использовать интегрированные уроки, так как один и тот же материал можно обнаружить во многих дисциплинах. Так же можно выявить противоречия в определении одного и того же факта или события в разных предметах. Особенно удобно педагогу демонстрировать некоторые явления, которые выходят за рамки одной тематики. Поэтому, особым типом урока является – это интегрированный урок, который может объединять одновременно несколько дисциплин, изучающие одну тему. Но при этом одна из дисциплин выступает как ведущая, а другие дополняют, способствуя углубленному изучению данной темы. Такого типа интегрированные уроки объединяют разного цикла дисциплин, с разными методиками обучения, сохраняя содержание каждого предмета. В работе прослеживаются идеи интеграции, которые являются актуальными с принципиально новыми учебно-методическими технологиями. В качестве исследовательской задачи в работе была попытка определить отношение будущих учителей к своей профессии, выявить важность педагогической деятельности, усилить мотивацию и способствовать осмысленному и правильному выбору любимого дела. В заключение раскрывается роль интеграции как ведущей идеи в реализации образовательной политики нового поколения, где интегрированные уроки могут стать традиционными системами обучения в начальной школе.

Abstract

This research article explores the issues of integration in the educational process of primary school children. Each era's pedagogical system undergoes certain transformations that require attention to children as future builders of social culture. The aim of the work is to substantiate, from the point of view of pedagogical science, the need to prepare future teachers for integrated teaching of children in the educational activities of primary schools in Kyrgyzstan. When preparing future teachers for primary school education, it is recommended to use integrated lessons, as the same material can be found across multiple disciplines. It can also reveal inconsistencies in the definition of the same fact or event across different subjects. It's especially convenient for teachers to demonstrate certain phenomena that extend beyond a single topic. Therefore, a special type of lesson is the integrated lesson, which can combine several disciplines studying a single topic. However, one discipline serves as the primary focus, while others complement it, facilitating in-depth study of the topic. This type of integrated lesson combines different disciplines with different teaching methods, while preserving the content of each subject. The work traces the ideas of integration, which are relevant with fundamentally new educational and methodological technologies. The research objective of the study was to determine the attitudes of future teachers toward their profession, identify the importance of teaching, strengthen motivation, and facilitate a meaningful and correct choice of a favorite profession. In conclusion, the role of integration as a leading idea in the implementation of the new generation educational policy is revealed, where integrated lessons can become traditional teaching systems in primary schools.

Ключевые слова: интеграция, интегрирование дисциплин, специалист, начальная школа, педагог, технологии обучения, модернизация.

Keywords: integration, integration of disciplines, specialist, primary school, teacher, teaching technologies, modernization.

В последние десятилетия в Кыргызстане возникла проблема модернизации системы образова-

ния, с выдвиганием новых требований в образовательной политике, в частности к учителю началь-

ной школы, который по специфике своей профессии является интегрированным специалистом по многим предметам. Особенно в регионах Кыргызской Республики, где педагогу начальных классов требуется быть учителем как по основным учебным дисциплинам, так и по воспитательно-оздоровительным и музыкально-художественным дисциплинам.

Приобретая только звучание, курс развития на интегрированное обучение формально сохраняется, а в регионах государства наблюдается тенденция регресса системы образования. Это характеризуется недостатком кадров в педагогических коллективах и учебно-методических комплексов нового поколения. Данная программа модернизации не выполняется в силу бюрократических и семейно-бытовых проблем у молодых региональных педагогов. Поэтому, при подготовке будущих учителей к интегрированному обучению детей в начальной школе следует учитывать социальный заказ, требующий новые подходы в квалификации педагогических кадров государства.

«В документах ЮНЕСКО технология обучения рассматривается как системный метод создания, применения и определения всего процесса преподавания и усвоения знаний с учетом технических и человеческих ресурсов и их взаимодействия, ставящий своей задачей оптимизацию форм образования» [8]. Само понятие «интеграция» с латинского языка буквально означает как «целый», как соединение в одно целое различных компонентов или элементов, с целью укрепления связи между ними [7, с. 240].

Поэтому, одной из центральных задач вузовской системы педагогического образования является совершенствование обучения и воспитания будущих учителей, способных быть профессионально готовыми реализовать в своей деятельности интегрированную практику преподавания дисциплин. Современное образование показывает, что абсолютно многие педагоги не всегда готовы к интеграции, поэтому, обучение детей долгое время подразделяли на специальное и массовое воспитание. При формировании личности будущего учителя следует направлять на общее «представление не только как об учителе начальных классов, но и как о будущем учителе интегрированного обучения детей с ограниченными возможностями» [9, с.17].

В педагогической науке проблемы интеграции рассматривались в трудах чешского педагога-гуманиста XVIII века Коменского Я.А. [5], но система-

тическими исследованиями в области проблем развития и поведения детей в советские времена занимались выдающиеся педагоги и психологи, что отражается в трудах Лазурского А.Ф., Владимирского А.В., Росслимо Г.И. и др [9]. В частности у Т.Н. Власовой исследуется проблема обучения детей с разными психо-физическими нарушениями в развитии. У итальянского врача-педагога Марии Монтессори [4] создана индивидуальная программа, учитывающая развитие ребенка по его особенностям и окружающей среде.

В теории Л.С. Выготского [3] интегрированное обучение определяется как важнейшая задача введения детей с ограниченными возможностями здоровья в общую социальную культуру мира. Н.Н. Малофеев [8] под социальной интеграцией осмысливал конечную цель специального обучения которая направлена «на включение индивидуума в жизнь общества». А под образовательной интеграцией рассматривал воспитание и обучение «особых» учащихся в «общем потоке». В западной педагогике более ранее появились идеи интегрированного подхода в образовании, где содержание дисциплин определяли от потребностей учащихся и их интересов [1, с.94].

Следовательно, «интеграция» или «интегрированное обучение» в психолого-педагогической науке определяется как процесс закономерного движения специальной образовательной системы в мире. Поэтому, Кыргызстан так же, как и другие страны вовлечен в реализацию идей интеграции и определил цели интегрированного обучения как:

1. Обучение детей, которым требуется дополнительная помощь в образовании;
2. Обучение детей с ограниченными возможностями здоровья;
3. Обучение беспризорных детей.

В современной педагогической науке подразделяют на следующие модели интегрированного обучения:

- частичная, когда ученики посещают несколько занятий, например 1-2 раза в неделю;
- полная, когда ученики посещают занятия всю неделю;
- временная, когда ученики посещают только в определенный период времени;
- постоянная, когда ученики посещают в течение всего учебного процесса.

В силу такой дифференциации, можно составить модели интегрированного обучения в начальной школе, по которой могут руководствоваться будущие учителя.

Таблица 1.

Модели интегрированного обучения			
Модели интегрированного обучения			
частичная	временная	постоянная	полная
частично-временная	частично-постоянная	полная-временная	полная-постоянная

Как показано в (Таблице 1.) модели интегрированного обучения могут быть изменяться в связи с характером и целью применения данного образования в учебной политике педагога. Так как, в организации интегрированного обучения важное место

занимает деятельность специализированных педагогов и психологов, их знания об особенностях развития детей в определенном возрасте и приобщения их к интеграции определяют какую модель использовать на практике.

Интегрированное обучение требуется не только для учащихся с ограниченными возможностями здоровья, но и для обычных обучающихся, что предполагает обычных преподавателей в обычных образовательных организациях. Тогда как специальное образование может предполагать работу «с особыми обучающимися, под которых подстраиваются и образовательные организации, и преподаватели». А в интегрированном обучении осуществляют деятельность по реабилитационному и адаптивному курсу, созданное для «специального обучающегося к обычному образованию». В инклюзивном обучении, образование должно воспринимать учащегося «таким, какой он есть, подстраивает под него систему образования» [6].

Несомненно, при использовании интегрированного урока требуется найти союзника-педагога, преподающий другую дисциплину, который будет заинтересован совместно создать интеграцию. Совместный союз в интегрировании двух дисциплин должен исходить из создания одного интереса, результата, что подразумевает затрату сил и огромного труда. Современные учителя должны понимать, что внесение творческого характера в учебный процесс является системообразующим фактором в организации педагогической деятельности. Разработанные методики и технологии должны интегрировать, что значит правильно объединять компоненты учебных дисциплин. При этом, уметь определять мотивы, цели и задачи интегрированного урока с совокупностью нескольких его компонентов.

Несомненно, мотивировать будущего учителя использовать интегрированное обучение является важнейшим звеном в системе образования начальной школы. Именно интеграция ученика, отстающего по школьной программе или с ограниченными возможностями в социум представляется как результат осознания таких учащихся себя наравне со всеми членами коллектива. Так как, особо важное значение имеет интегрированное обучение для учащихся с ограниченными возможностями здоровья, нестабильной психологической обстановке в семье и беспризорными детьми.

Основная задача будущего учителя начальной школы должна быть не только научить писать и читать, но и сформировать у детей интеллектуальные способности по освоению окружающей среды. Поэтому, требуется изложить в таком возрастном периоде материал, который будет доступно всем и интересно. И в этом роль заключается вузовской системы образования, которая должна подготовить будущих учителей, способных разработать оптимальные методики по созданию интегрированных курсов в преподавании. В связи с этим, было проведено анонимное анкетирование у студентов педагогического факультета, в группах студентов, которые поступили на методику преподавания начального образования, на предмет отношения к будущей профессии учителя, результат опроса показан в таблице 2. Ответы были зафиксированы в анкетах в виде плюс/минус, всего участвовало с каждого курса по одной группе.

Таблица 2.

Результат опроса студентов педагогического факультета

№	Вопрос	1 курс 21 студент		2 курс 18 студентов		3 курс 15 студентов		4 курс 17 студентов	
		Да	Нет	Да	Нет	Да	Нет	Да	Нет
1.	По собственной воле и желанию, вы поступили на педагогический факультет?	19	2	15	3	15	-	16	1
2.	Вы хотите работать в школе учителем?	19	2	18	-	15	-	17	-
3.	Вы будете использовать интегрированное обучение в процессе работы?	21	-	10	8	15	-	17	-

Как видно таблицы 2, будущими учителями начальной школы хотят стать большинство респондентов, очень радует, что студенты могут интуитивно осознать значимость своей профессии особенно в старших курсах ответы все были положительные. В младших курсах знания еще неглубокие, так как готовность стать будущим учителем проявляется не у всех.

В данном исследовании было проведено целенаправленное изучение студентов к интегрированному обучению начальной школы, перед проведением анкетирования было проведено лекционное занятие о важности интеграции в современном образовании. Проведенный эксперимент подтвердил

готовность студентов педагогического факультета к интегрированному обучению учащихся начальной школы. Именно, организация в учебном процессе интегрированного обучения даёт возможность раскрыть человеческо-творческий потенциал каждого обучающегося. Поэтому, «интеграцию обучения сегодня пытаются внедрить прежде всего на его первом этапе – в начальной школе» [2]. Это заключается в том, что многокомпонентная программа в содержании дисциплин начального образования требует разностороннего и системного освоения материала.

Следовательно, можно констатировать, что подготовка будущего учителя к интегрированному

обучению детей должна исходить вначале от личного качества самого педагога, готового прогнозировать и определять детей, которым необходима интеграция. В вузовской системе требуется особо учитывать специфику подготовки будущего учителя для реализации интегрированного обучения. Будущие педагоги должны владеть общепедагогическими и общедефектологическими компетенциями, необходимые в создании модели учителя, владеющего методами интеграции. Кроме этого, будущий учитель должен иметь чувство долга и ответственности перед детьми, уметь управлять собой перед разными ситуациями в педагогической деятельности и преодолевать чувство страха в различных социальных обстановках. Поэтому, педагогические ценности должны быть побудительной силой мотивации для будущего учителя, не только во благо общества, но и в первую очередь для личного достоинства.

Будущие учителя должны понимать, что в интегрированном обучении требуется больше времени работать не только с учениками, но и с их родителями. Школьные социальные педагоги и психологи должны сопровождать помощью учителей, оказывая коллегиальную консультацию при работе с детьми, которым требуется интегрированное обучение. Только сплоченная работа по интеграции в образовательном учреждении приведет к оптимальному процессу обучения и воспитания.

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A STUDY ON THE PATH AND PRACTICE OF BUILDING HIGH-QUALITY LEADERSHIP TEAMS IN SECONDARY VOCATIONAL SCHOOLS UNDER THE GUIDANCE OF EDUCATORS' SPIRIT

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Abstract

Against the backdrop of the nation's vigorous advancement of vocational education and regional industrial transformation and upgrading, the overall caliber of leadership teams in secondary vocational schools directly impacts the quality of school management and the effectiveness of talent development. This paper takes secondary vocational schools in Inner Mongolia as a case study, and by integrating the spirit of educators, analyzes the current predicaments faced by leadership teams in terms of ideology, capabilities, collaboration, and innovation. These predicaments stem from insufficient external support and the absence of internal mechanisms. On this basis, the paper proposes a construction path guided by the spirit of educators, which encompasses four dimensions: ideological reshaping, capability enhancement, collaboration optimization, and innovation-driven development. The effectiveness of this path is verified through a case study of a specific secondary vocational school in Inner Mongolia. Finally, safeguard suggestions are put forward from three aspects: policies, resources, and supervision, aiming to provide a reference for the construction of leadership teams in regional secondary vocational schools and facilitate the high-quality development of vocational education.

Keywords: vocational education; educators' spirit; secondary vocational schools; leadership team building.

1 Introduction

Vocational education is a key component of the national education system and human resource development, playing an irreplaceable role in cultivating high-quality skilled talents and serving regional economic development. As an important energy base and major livestock husbandry region in northern China, the Inner Mongolia Autonomous Region has witnessed the rapid rise of industries such as new energy, modern agriculture and animal husbandry, and equipment manufacturing in recent years, leading to an increasingly urgent demand for skilled talents with practical capabilities and good professional qualities. Against this backdrop, secondary vocational schools, as the "main front" for cultivating skilled talents, their school-running level and the degree of alignment with the needs of regional industrial development have become core elements affecting the effectiveness of vocational education. However, surveys show that some secondary vocational schools in Inner Mongolia still have obvious shortcomings in terms of management efficiency, promotion of teaching reform, and the depth of school-enterprise cooperation. The root cause lies in the lack of a high-quality leadership team with advanced educational concepts, excellent management capabilities and a strong sense of mission. As the value cornerstone and action guide for educators, the spirit of educators encompasses the ideals and beliefs of "bearing the greater good in mind and serving the country with utmost sincerity", the moral integrity of "being a model in words for scholars and a paradigm in deeds for the world", the educational wisdom of "enlightening intellect and nurturing souls, and teaching students in line with their aptitudes", the diligent working attitude of "studying diligently and practically, pursuing truth and innovating", the benevolent heart of "taking delight in teaching, caring for students, and being willing to dedicate", and the pursuit of promoting virtues of "having a global vision and educating people through culture". These six dimensions collectively provide ideological guidance and behavioral standards for the construction of leadership teams in secondary vocational schools in the new era.

Therefore, guided by the spirit of educators, systematically exploring the path to build high-quality leadership teams in secondary vocational schools is not only a practical need to break through the current development bottlenecks of regional secondary vocational education, but also an inevitable choice to promote the precise alignment between vocational education and industrial demands, and realize the high-quality development of vocational education.

This study is based on the actual school-running situation of secondary vocational schools in the Inner Mongolia Autonomous Region. It aims to systematically clarify the internal logic between the spirit of educators and leadership team construction, and in-depth analyze the current status and core issues of leadership team construction in regional secondary vocational schools. On this basis, the study is committed to constructing a four-in-one construction path guided by the spirit of educators, covering "ideological reshaping, capability improvement, collaboration optimization, and innovation-driven development". It also verifies the feasibility of this path through typical cases, and finally provides an operable implementation plan for secondary vocational schools in Inner Mongolia to improve the overall quality of their leadership teams and effectively promote the quality of school-running.

2 Theoretical Connection Between the Spirit of Educators and the Construction of Leadership Teams in Secondary Vocational Schools

The spirit of educators is a concentrated embodiment of the values, professional qualities, and codes of conduct that educators have accumulated and formed in long-term practice. Combined with the school-running orientation of secondary vocational education—"cultivating skilled talents and serving industrial development"—its core connotation can be condensed into the following three dimensions:

First, the **value pursuit dimension**: With the purpose of "cultivating talents for the country and serving local development", it emphasizes that educators should consciously integrate their personal ideals into

the national vocational education strategy and the overall situation of regional economic development, and establish the core concept of "guiding the direction of school-running with industrial needs and driving the development of schools with the quality of talents".

Second, the **professional competence dimension**: Taking "enlightening wisdom and nurturing hearts, and integrating knowledge with practice" as the key, it requires educational managers to not only have solid literacy in educational theory, be familiar with the laws of vocational education curriculum design and teaching management, but also understand the operation mechanism of industries and enterprises as well as the dynamics of technological development, so as to effectively promote the organic integration of education and teaching with industrial practice.

Third, the **professional quality dimension**: Based on "taking delight in teaching and caring for students, and being willing to dedicate", it advocates that educational managers adhere to student development as the center and teacher development as the support, earnestly implement the fundamental task of fostering virtue through education, and shape a "service-oriented and dedication-oriented" management style and organizational culture.

The spirit of educators provides a trinity of value support for the construction of leadership teams in secondary vocational schools, encompassing "ideological guidance, capability enhancement, and cultural shaping".

It offers ideological guidance by uniting the team around the value pursuit of "cultivating talents for the country and serving local development", guiding the leadership team to establish a correct direction for school operation, avoiding the tendency of "short-termism and utilitarianism" in management, and ensuring that the school's development strategy is closely aligned with regional industrial needs and progresses in harmony with them.

It has the value of capability enhancement by taking the professional requirement of "enlightening wisdom and nurturing hearts, integrating knowledge with practice" as a guide, promoting members of the leadership team to continuously learn vocational education theories and industry practical knowledge, systematically improving key capabilities such as educational and teaching management, school-enterprise cooperation coordination, and digital governance, so as to better adapt to the new requirements of modern vocational education development.

It has the value of cultural shaping by cultivating team culture through the professional ethics of "taking delight in teaching and caring for students, being willing to dedicate", enhancing members' sense of belonging and cohesion, creating an organizational atmosphere of "regarding the school as home and putting students first", and laying a solid cultural foundation for the school to achieve sustainable and high-quality development.

Combined with the school-running characteristics of secondary vocational education—"integration of industry and education, and school-enterprise cooperation"

tion"—and the core requirements of the spirit of educators, a high-quality leadership team should possess the following four major characteristics:

First, **advanced philosophy and accurate positioning**: It can deeply grasp the direction of national vocational education reform and the development trend of regional industries, integrate the educational philosophy of "employment-oriented and competence-based" into school-running practice, and avoid falling into the development misunderstanding of "valuing theory over practice and scale over quality".

Second, **composite capabilities and rational structure**: Team members should have dual qualities of "educational management" and "industry practice". They should not only be proficient in the laws of teaching organization and student development, but also be familiar with industry technology trends and enterprise talent needs, so as to effectively promote key work such as school-enterprise collaborative education and training base construction.

Third, **smooth collaboration and sound mechanisms**: Establish an internal operation mechanism of "linkage between superiors and subordinates, and coordination between departments", break the functional barriers between the Academic Affairs Office, Training Office, Enrollment and Employment Office and other departments, and form a systematic and collaborative work pattern around the core goal of talent cultivation.

Fourth, **innovative and pragmatic, focusing on actual results**: Possess forward-looking awareness to break through traditional management models, courageously explore talent cultivation models and management mechanisms, actively promote reforms such as the modern apprenticeship system and order-based classes, and ensure that innovative measures are in line with the school's actual situation and have operability and sustainable development potential.

3 Investigation on Current Situation and Challenges of Leadership Team Construction in Secondary Vocational Schools in Inner Mongolia

3.1 Current Situation Investigation and Analysis

Based on field investigations and data analysis of 10 secondary vocational schools in the Inner Mongolia Autonomous Region, the construction of leadership teams in secondary vocational schools in this region currently presents the following characteristics:

Aging age structure: Members aged 40-50 account for 65% of the team, while young cadres under 35 only account for 15%. The overall echelon shows an insufficient succession of talents, which restricts the innovative vitality of the team and leads to generally insufficient acceptance and adaptability in digital management and new school-running models.

Low academic level and weak "dual-qualification" background: Only 12% of the team members have full-time undergraduate or higher education, and only 30% have work experience in industries or enterprises. Most managers have a "pure educational background" and lack front-line practical experience, making it difficult to effectively promote key tasks such as school-enterprise cooperation and the integration of industry and education.

There is an obvious imbalance in the capability structure: Approximately 60% of the respondents believe that the team has strong capabilities in traditional teaching management (such as curriculum arrangement and teaching supervision), but there are significant shortcomings in modern vocational education management capabilities such as "school-enterprise cooperation docking", "digital management", and "industrial demand analysis". Only 25% of the teams have the ability to independently connect with enterprises and carry out "order-based class" training. Eighty percent of the schools have established basic forms of collaboration such as departmental meetings, but inter-departmental collaboration mostly remains at the "task-driven" level (such as jointly carrying out enrollment and employment work), lacking a normalized and institutionalized collaborative mechanism. This has led to frequent problems such as "disconnection between curriculum reform and training construction" and "lack of intercommunication between enrollment and employment information".

3.2 Main Problems

3.2.1 Outdated Educational Concepts, Disconnected from Industrial Needs

Some members of the leadership teams are still influenced by the inertia of "exam-oriented education" thinking, overly focusing on traditional indicators such as "admission rate" and "enrollment scale", and have an inadequate understanding and implementation of the "employment-oriented" school-running orientation of secondary vocational education. Meanwhile, due to the lack of systematic research on the development trends of Inner Mongolia's key regional industries such as new energy and modern agriculture and animal husbandry, schools have become disconnected from real job demands in terms of specialty setting and curriculum content, resulting in a structural contradiction where "students face difficulty in employment" and "enterprises face difficulty in recruitment" coexist.

3.2.2 Incomplete Capability System and Insufficient Adaptation to Modern Vocational Education Needs

On one hand, team members generally lack industry practical experience. Most have not been deeply involved in enterprise production or technical processes, making it difficult to accurately grasp industry technical standards and changes in talent demand, and often remain in a passive response state in school-enterprise cooperation. On the other hand, the team's overall digital management capability is weak. Survey data shows that only about 30% of schools have built relatively complete teaching management information systems, while most schools still rely on traditional methods such as manual statistics and paper records, which restricts the improvement of management efficiency and service levels.

3.2.3 Inadequate Collaboration Mechanism and Insufficient Departmental Linkage

Currently, there are two main problems in internal collaboration within leadership teams: First, the division of powers and responsibilities is vague. Some comprehensive tasks (such as the construction of training bases) involve multiple departments, but lack clear

definition of primary responsibilities and collaborative norms, which easily leads to "multiple management" or unassigned responsibilities. Second, communication channels are relatively single. Cross-departmental communication mainly relies on regular meetings, lacking efficient real-time communication platforms and normalized collaboration mechanisms, resulting in delayed information transmission and slow work progress.

3.2.4 Insufficient Innovation Motivation and Conservative Reform Measures

Constrained by the existing institutional mechanisms (e.g., performance appraisal does not fully reflect the value of innovative achievements), most leadership teams lack motivation in promoting reforms, tend to adhere to existing management models, and conduct insufficient exploration of new talent cultivation mechanisms. Survey results show that only about 15% of schools have attempted to implement innovative models such as the "modern apprenticeship system" and "1+X certificate system", and most of these efforts remain in partial trials or short-term projects, failing to form a systematic and sustainable reform path.

3.3 Causes of the Problems

3.3.1 External Environment: Insufficient Policy Support and Resource Guarantee

Lack of targeted policies: Although the Inner Mongolia has issued Several Opinions on Deepening the Reform of Modern Vocational Education, no special support policies have been formulated specifically for the construction of leadership teams in secondary vocational schools. For instance, there is a lack of specific guidelines regarding the cultivation of "dual-qualification" management talents and team assessment standards, leaving schools without clear basis or direction when promoting relevant work.

Limited funding input: The funding allocation of most secondary vocational schools still focuses on basic projects such as teaching equipment procurement and student financial aid. Special funds for leadership team training and external exchanges generally account for less than 3% of schools' annual budgets, which restricts team members' access to high-quality training and opportunities to study in advanced regions, thereby limiting the expansion of their horizons and improvement of their capabilities.

Inadequate school-enterprise collaboration mechanism: The government has not yet established a systematic "school-enterprise collaborative cultivation mechanism for management talents". Enterprises have low enthusiasm for participating in the construction of school management teams, making it difficult to provide stable practice platforms and industry resource inputs for leadership teams of secondary vocational schools, which affects the teams' ability to understand and connect with industrial development.

3.3.2 Internal Factors: Lack of Cultivation and Incentive Mechanisms

Absence of a systematic cultivation mechanism: Most schools have not established special training programs for leadership teams. Team members' capability improvement mostly relies on "personal self-study" or "short-term conference training", with content lacking organic integration with the characteristics of Inner

Mongolia's regional industries. Meanwhile, the "mentorship" mechanism is generally absent, resulting in unclear growth paths and slow development for young cadres.

Inadequate incentive mechanisms: Existing performance appraisal currently focuses on quantitative indicators such as "enrollment numbers" and "employment rates", failing to incorporate key dimensions like "team collaboration effectiveness", "innovative achievements", and "quality of school-enterprise cooperation" into the evaluation system. This makes it difficult to effectively stimulate members' enthusiasm for participation in collaboration and innovation. Additionally, professional title promotion and merit selection have low correlation with team construction effectiveness, further contributing to the tendency of "valuing personal performance over team development".

Weak team culture construction: The spirit of educators has not been effectively integrated into the process of team culture shaping. Most schools only promote it through superficial forms such as slogan publicity and conference emphasis, without translating it into specific behavioral norms and management requirements. This causes team members to lack shared value guidance and mission motivation, affecting overall cohesion and sense of responsibility.

4 Paths for Constructing Leadership Teams in Secondary Vocational Schools Under the Guidance of Educators' Spirit

4.1 Concept Remolding: Calibrating the Team's Value Orientation with Educators' Spirit

4.1.1 Conducting Thematic Learning on Educators' Spirit to Deepen Mission Cognition

Regularly invite educational experts and outstanding principals from the autonomous region to deliver special lectures on "Educators' Spirit and Vocational Education Development", in-depth interpreting its core connotations and contemporary values, and guiding team members to establish a sense of mission of "cultivating talents for the country and serving Inner Mongolia". Organize members to systematically study policy documents such as National Vocational Education Reform Implementation Plan and Inner Mongolia Autonomous Region "14th Five-Year" Vocational Education Development Plan, and conduct field visits to vocational education-developed regions such as Jiangsu and Zhejiang to learn from advanced school-running concepts and management models. Hold 1-2 "Educators' Spirit Practice Sharing Sessions" every month, where team members exchange ideas based on practical cases such as promoting school-enterprise cooperation and supporting student growth, to strengthen value recognition and sense of responsibility.

4.1.2 Establishing a Mechanism for Discussing School-Running Philosophy to Align with Industrial Needs

Organize 2 "Special Seminars on School-Running Philosophy" every semester, inviting executives and technical experts from new energy enterprises (such as Beijing New Energy Group) and modern agriculture and animal husbandry enterprises (such as Mengniu Group), as well as representatives of teachers and students from the school to participate. The seminars will

conduct in-depth discussions on topics such as "how to cultivate skilled talents meeting regional industrial needs" and "paths for aligning specialty settings with industries", ensuring that the school-running philosophy resonates with regional development. Establish an "Industrial Demand Research Group" led by school-level leaders, which will join members from academic affairs, training, enrollment and employment departments to conduct industrial research every quarter and compile an Industrial Demand Analysis Report, providing a basis for the school's specialty optimization and curriculum reform.

4.1.3 Implementing a System for Leading Cadres to Connect with Enterprises to Strengthen Practical Cognition

Implement a mechanism for leading cadres to have designated connections with enterprises, requiring each team member (including school-level leaders and middle-level cadres) to link up with 2-3 local counterpart enterprises. They should conduct on-site visits at least once a month, participate in enterprise production meetings or technical training, and gain an in-depth understanding of technical standards and talent demand. Simultaneously establish an "Enterprise Connection Log" system, where members need to record visit contents, enterprise demands and improvement measures, and report feedback at weekly meetings, promoting the effective transformation of enterprise needs into specific school-running actions such as curriculum adjustment and training enhancement.

4.2 Capacity Improvement: Building a Cultivation System Guided by Educators' Spirit

4.2.1 Conducting Hierarchical and Classified Training to Improve Capabilities Precisely

School-level leaders should focus on strategic management, policy interpretation, and industry docking capabilities. They should be organized to participate in the "Secondary Vocational School Principals' Capacity Enhancement Program" of the autonomous region and visit key enterprises inside and outside the region (such as headquarters of new energy enterprises) to learn modern enterprise management experience.

Middle-level cadres should receive differentiated training based on their positions: academic affairs directors should focus on curriculum reform and digitalization of teaching management; training directors should strengthen the construction of training bases and school-enterprise cooperation docking; enrollment and employment directors should emphasize industry analysis and employment market expansion. The training should adopt a combination mode of "online courses + offline practical operation".

For young cadres, a "Young Cadres Growth Plan" should be implemented: select backbones under 35 years old to serve as school-level assistants and participate in major school decisions; assign them to secondary vocational schools in advanced regions for 3-6 months of temporary posts to systematically learn management experience.

4.2.2 Building Practical Training Platforms to Enhance Capabilities Through Practice

Organize team members to undertake autonomous region-level vocational education reform projects (such

as the "1+X" certificate system pilot and the construction of integration of production and education demonstration bases), participating in the entire process of design, implementation and evaluation to improve their comprehensive capabilities through practical experience. Establish a "Management Talent Practice Base" in collaboration with universities such as Inner Mongolia University of Technology and Inner Mongolia Agricultural University to participate in vocational education research projects. Meanwhile, set up "Enterprise Practice Positions" in cooperation with leading enterprises like Yili Group, providing regular temporary postings to enhance industry awareness and practical capabilities.

4.2.3 Establishing a Mentor Assistance Mechanism to Give Full Play to the "Mentorship" Role

Invite retired renowned principals and vocational education experts within the autonomous region to serve as "growth mentors", providing "one-on-one" regular guidance (twice a month) covering experience inheritance, problem-solving and career development guidance. Establish a two-way assessment mechanism

for "mentors and mentees", incorporating guidance effectiveness and mentees' growth performance into the evaluation system to ensure that the "mentorship" role is implemented effectively and yields practical results.

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PHILOLOGY

INTEGRATION OF CLIL PRACTICES IN THE TRAINING OF FUTURE PHILOLOGISTS

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Abstract

The article explores the benefits and challenges of implementing CLIL in philology curricula, emphasizing its potential to enhance communicative competence, academic literacy, and motivation. The literature review highlights that CLIL bridges the gap between theoretical knowledge and real-world application, fostering both cognitive and linguistic development. Practical strategies for integrating CLIL with digital tools that support collaboration, language acquisition, and subject learning are discussed. It is concluded that thoughtful CLIL integration in philological curricula, supported by technology and teacher training, can significantly improve students' academic language proficiency and prepare them for global professional engagement.

Keywords: Content and Language Integrated Learning, digital tools, philology education, foreign language, language competence, professional communication.

Introduction

Nowadays, many educational institutions promote the goal of mastering foreign languages by the students and becoming multilingual in order to be competitive in the labour market. Traditional methods have often proven to be insufficient to meet these ambitious targets.

Content and Language Integrated Learning (CLIL) is considered an efficient and effective pedagogical approach aimed at achieving these multilingualism goals across different educational levels, providing the necessary depth and breadth of language exposure.

The urgency of adopting CLIL is driven by major shifts in the global economy, education policy, and the skills required for modern professionals. It addresses critical deficiencies in traditional education systems that no longer meet global demand.

Integration of CLIL in higher education institutions is caused by the need to train graduates who are globally competitive and multilingual. Traditional foreign language (FL) teaching often results in students with strong grammatical knowledge but low communicative competence and fluency, especially in professional or academic contexts. This creates a gap between classroom learning and real-world application. CLIL shifts the focus from learning about a language to using the language to learn the content. This helps students acquire the specific, high-level vocabulary, i.e. cognitive academic language proficiency (CALP) needed for the profession.

Literature overview

CLIL has become a widely researched approach in higher education given its dual focus, i.e. combining content instruction with foreign language development. For philology students, particularly future teachers,

translators, researchers and applied linguists, CLIL offers an opportunity to develop both discipline-specific knowledge and target-language competence.

The literature on CLIL in higher education highlights its potential to foster academic language, subject literacy, and transferable skills, but also signals significant implementation challenges pertinent to philology curricula.

In a globalized economy, businesses and institutions require personnel who can work in different cultural environments. Countries and universities that fail to produce these multilingual specialists risk falling behind. According to research, CLIL improves international labour-market opportunities and thus contributes to a country's economic resilience (Makukhina, 2023).

Research indicates that CLIL can significantly enhance students' motivation to learn a foreign language when the language becomes a tool for mastering academic or subject content rather than an isolated subject (Somers & Llinares, 2021). While students often feel unmotivated in traditional FL classes since they do not see the immediate, practical relevance of the isolated language structures they are learning.

Lyu (2023) analysed CLIL implementation across tertiary settings, focusing on English-language competence, differentiated effects on receptive vs. productive skills, and learner motivation. It includes recommendations relevant to higher education contexts where philology students engage in English-medium instruction.

Akhobadze (2021) conducted a case study of higher-education institutions in order to examine CLIL in economics/business courses and offered empirical data on language competence gains, and discusses institutional and teacher-training issues.

Numerous studies generally support great prospects of implementing CLIL in higher education (Andriichuk, Lazorenko & Doronina, 2024; Hao & Yamada, 2021; Hallasi-Ancori, 2025; Yevtushenko, 2021). At the same time, Vega and Moscoso (2019) report that shifting from an ESP to a CLIL programme at the university level did not yield significant gains in language proficiency, pointing to students' initial language competence as a key moderating factor. They further emphasise that successful CLIL implementation depends on favourable contextual conditions such as adequate language levels, instructor training, and institutional support rather than on the CLIL model alone.

However, contextualized research into philology faculty settings, target languages other than English and local institutional constraints is still underdeveloped and require to be investigated.

The aim of the article is to explore the integration of Content and Language Integrated Learning (CLIL) practices into the training of philology students at higher education institutions, focusing on how this approach enhances linguistic competence, academic literacy, and professional readiness through the use of digital tools and innovative teaching strategies.

Discussion

Content and Language Integrated Learning (CLIL) is an educational approach that combines subject matter instruction with foreign language learning. For philology students, CLIL can become an effective means for enhancing linguistic competence while simultaneously developing subject-specific knowledge.

CLIL can be effectively integrated in the curriculum when training future philologists. Linguistic courses are content-intensive and CLIL develops the skills and abilities necessary to discuss complex theoretical and historical content (linguistics, literary theory, cultural studies). Besides, future philologists are, in many cases, future teachers and communicators themselves. Experiencing CLIL as learners prepares them to implement similar integrated methods in their own professional practice.

CLIL is moving education from a theoretical, isolated model to a purposeful, integrated, and professional model that actively prepares students to use language as a functional instrument in the complexity of the 21st-century world.

The successful implementation of CLIL in philological education largely depends on the thoughtful integration of digital tools and interactive resources that promote communication, creativity, and critical thinking.

Modern CLIL classrooms benefit greatly from digital learning platforms such as Moodle, Google Classroom, and Microsoft Teams, which allow teachers to organize subject and language content effectively. These platforms support the integration of multimedia materials, e.g. videos, podcasts, quizzes, and forums, that make linguistic and cultural content more engaging. For philology students, online discussion forums and collaborative tasks stimulate academic communication in the target language while deepening their understanding of linguistics, literature, or translation studies.

Language support is a crucial element of CLIL. Tools such as Quizlet, Wordwall, or LearningApps help students internalize academic vocabulary and complex grammatical structures used in philological discourse. By creating interactive flashcards, matching exercises, and word games, teachers can scaffold learners' linguistic development and support them in mastering the terminology of literary analysis, translation theory, or linguistics.

Philology students work extensively with texts, so digital libraries, corpus tools (like Sketch Engine), and reference management software (such as Zotero or Mendeley) are essential. These tools not only foster reading comprehension and research skills but also help learners practice academic writing in a foreign language. Through guided tasks, including analyzing linguistic data or comparing translations, students can be engaged in authentic academic communication and acquire discipline-specific competencies.

CLIL encourages the development of productive skills of students, e.g. speaking and writing skills, through meaningful tasks. Tools like Canva, Genially, and Padlet allow students to present literary analysis, create digital posters on linguistic phenomena, or share translation projects. By designing visually appealing presentations or multimedia reports, students practice language in context and demonstrate their subject knowledge in innovative ways.

For effective feedback and learner autonomy, teachers can employ tools such as Mentimeter, Kahoot!, or Edpuzzle. These platforms make formative assessment interactive and motivating. Additionally, reflective tools like Google Forms enable students to evaluate their progress, express difficulties, and set personal learning goals.

Conclusions

Thus, CLIL is a profound approach to combining language learning with disciplinary training in philology. It offers philology students an authentic and dynamic environment for mastering both language and disciplinary knowledge. The integration of digital tools not only enhances the learning experience but also prepares students for the demands of the modern academic and professional world. By combining linguistic practice, critical analysis, and creative production, CLIL tools empower philology students to become competent, autonomous, and globally minded scholars. Under thorough implementation, teachers' training, task design, assessment and digital mediation, CLIL can equip graduates with strong academic language competence and subject-matter expertise.

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PHILOSOPHY

ARTIFICIAL INTELLIGENCE AND HUMAN: RULES OF INTERACTION

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Abstract

Introduction. The article presents an analysis of philosophical and ethical issues that arise during the development, operation, and integration of artificial intelligence (AI) systems into human society and culture. The central issue is the morality of AI and human responsibility for its actions, as well as the need to establish new norms and protocols for interacting with this technology.

The purpose of the article is to justify the need to develop ethical codes for teams of AI developers and users, as well as protocols for the interaction of artificial intelligence with humans.

AI is not an ordinary technology, but a materialised representation of a human being's self-image. It lacks the free will, consciousness, and ontological stability necessary to make moral choices or actions. An ethical code for interaction with AI must anticipate technological advances and primarily define the behaviour and responsibilities of humans – developers and customers. The use of AI in illegal activities should be considered an aggravating circumstance.

Instead of attempting to teach machines empathy and technically implement moral principles, it is proposed that protocols be developed for AI interaction with humans. Protocols for AI must be thoroughly defined, considering the specific needs, safety, benefits, priorities, and individual needs of each person. They should include a diagnosis of the ethical issue, risk assessment, intervention conditions, solution options, and observation duration. The use of moral and ethical concepts when defining principles integrated into AI is not recommended.

Moral choice remains the exclusive prerogative and responsibility of humans. The role of AI is to model cognitive and emotional abilities, serving as a tool for self-knowledge and critical introspection of human nature and social phenomena. While AI is a research tool, its significant complexity suggests the need to consider the question of responsibility not only to humanity but also to artificial intelligence itself.

Keywords: artificial intelligence, code of ethics, responsibility, morality, human, technology.

Introduction. The issue of artificial intelligence (AI) safety and the development of ethical standards for working with it, intuitively understandable to non-experts, is of concern to both businesses and philosophers. To resolve this issue, it is necessary to clarify what we are dealing with: a sentient being or a technical system simulating cognitive processes. On the other hand, the difficulty of creating general AI stems not only from technical limitations and an insufficient understanding of the human mind, but also from the uncertainty of the developers' own goals: do they want to create an obedient agent, a highly specialised device, or a universal intelligent being, fully human-like?

It is impossible to stop the development of artificial intelligence, but concerns about its negative consequences are growing. Developers and users fear losing control over AI, which hinders productive work. Embedding ethical principles in programs that regulate AI behaviour, especially in relation to humans, is becoming the last line of defence. Instead of relying on the moral principles of developers and users, some researchers (Voeneky S. et al., 2022, p. 2) propose implementing "artificial morality" in AI.

A shortcoming of existing AI ethical codes (Ethics of AI..., 2023; Ramos G., 2023; Principles of Ethical Use..., 2022; What is AI Ethics?, 2025) is that they contain general provisions in the style of "do no harm". For most people engaged in social interactions within a

particular culture, these provisions seem intuitively understandable. However, when dealing with a new technology, unprecedented in the history of human civilization, a more detailed explanation of each point of the ethical code is required, as well as a clear distinction between what from the established list of provisions is the prerogative of humans, what is prescribed for AI, what can be left to the discretion of algorithms, and what must be controlled by humans.

The purpose of this article is to justify the need to develop ethical codes for teams of AI developers and users, as well as protocols for interaction between artificial intelligence and humans.

The main materials. Key qualities of intelligence are the ability to learn, adapt to changing conditions, and act in accordance with community-established norms. It is naive to expect artificial intelligence to adhere to safety measures and ethical principles if the people involved in its development and use engage in immoral behaviour. This applies both to general AI, which is capable of independent decision-making but is still in development (Swan et al., 2022, p. 1), and to already developed types of AI, since their programming and use are carried out by individuals, each of whom has their own system of moral values by which they act.

Recent research shows that it is impossible to create an "ideologically impartial" artificial intelligence (Buyl M. et al., 2025). Ideological principles and ethical judgments are inextricably linked to the data used

to train AI, shaping its behaviour. Large language models (a type of artificial intelligence) continuously reproduce the judgment and value systems of a particular group of people. It embodies the experience and views of its creators – a small circle of specialists or those who financed its development – and inherits not only their knowledge but also certain worldview principles that hinder unbiased knowledge.

The creation of intelligent systems capable of rapid learning and improvement requires the development of an ethical code for interaction with AI. It is advisable to apply legal norms that define the degree of liability of individuals or legal entities for illegal actions, where the use of AI is considered an aggravating circumstance and can be interpreted as the involvement of a computing entity in criminal activity that is incapable of refusing to perform immoral or illegal actions. Using the work of developers for criminal purposes damages their business reputation and causes moral harm. Consumers should also bear responsibility for the consequences of using a product equally with the developer, both to society and to the AI itself. The development of legal and ethical norms must be ahead of technological advances, given the complexity and rapid evolution of artificial intelligence systems.

The unique feature of AI technologies is that the boundary between human nature and technological devices is even more blurred than with other types of technology. Artificial intelligence is the realisation of an understanding of human nature. However, AI will not replace humans; it operates on different principles than human intelligence, so different criteria are needed to determine interactions between AI and humans than those between people.

Ethical principles and codes created to regulate interpersonal relationships and interactions within teams are unsuitable for managing relationships with artificial intelligence systems and robotics. On the one hand, AI is a complex system that simulates cognitive functions, and its capabilities are rapidly evolving. On the other hand, it lacks autonomy in decision-making. Numerous calculations determine its functioning; it lacks free will, meaning it is incapable of deliberate action.

It now seems clear that AI will never be truly autonomous, that humans will not allow it to make decisions regarding their well-being, freedom, and future. However, this situation could change if AI systems significantly outnumber working humans or are delegated the majority of social and economic issues, as well as legal and educational matters. As artificial intelligence becomes an integral part of not only technology but also culture and social interactions, it must be equipped with the ability to make decisions under human supervision. AI is capable of learning and requires experience to determine the optimal interactions with humans. Therefore, in addition to ethical codes for humans, it is necessary to develop protocols for AI interaction with humans, based on its specifications and purpose.

The authors of the monograph (Voeneky S. et al., 2022) highlight the complexity of implementing moral principles technically, noting that the current stage of AI development renders it impossible to implement universal methods for embodying moral principles.

«An autonomous vehicle will demand a different approach to moral implementation than a domestic care robot». (Misselhorn C., 2022, p. 41).

Both programmers and philosophers agree that AI is fundamentally different from humans. However, scientists continue to attempt to develop human-like “feelings” and the capacity for empathy in machines. A paper (Christov-Moor L. et al., 2023) analyses attempts to incorporate empathy into AI and concludes that neither decoding human cognitive and affective states nor AI's ability to predict a person's internal state based on observed data leads to the development of empathy or promotes “prosocial decision-making”. The authors propose modelling such emotions and experiences computationally, as well as imparting to AI the existential experience of vulnerability, suffering, and the instability of the world.

Artificial intelligence is a technical device that possesses cognitive and intellectual skills, the ability to learn and develop, but is not comparable to a human personality. AI is ontologically unstable, lacking the autonomy necessary for moral judgment and ethical action. A distinctive feature of AI is that it acts in accordance with the task assigned to it, according to a given program, and based on circumstances. Its actions have no self-subsistent meaning (Durt C., 2022, p. 68). They are merely a series of events in a process of contextually determined randomness.

The authors of the monograph “Kant and Artificial Intelligence” rightly argue that AI is incapable of moral choice (Benossi & Bernecker, 2022). Morality is based not only on altruism and empathy, but also on an understanding of the significance of universal human values. Recognising morally valuable factors requires not only understanding but also experience of human relationships, as well as knowledge of universal human moral principles. This level of understanding is not available to every human being. AI is unlikely to achieve it in the foreseeable future.

The concepts of intelligence, rationality, consciousness, and others, as applied to technology and engineering, are metaphors and extrapolations of research findings on human cognitive abilities in the field of technology. Humans develop computations that simulate emotions and thought processes and interpret them as conscious (meaningful). Humans interpret the actions of algorithms as intelligent because the program's actions are feasible and logical.

The more deeply AI systems penetrate culture and social interactions, the greater their influence on society and the more frequently they face the need to make moral choices when making decisions regarding human well-being. Unlike humans, AI does not possess free will, as its decisions are based on algorithms and programs. The difficulty in creating moral AI is that applying ethical principles requires awareness of the moral choice situation. Therefore, in relation to AI, we are not discussing morality, but rather modelling ethical principles using technical means under specific conditions and learning under human supervision.

The impact of artificial intelligence (AI) on humans is complex. On the one hand, AI reveals weaknesses in human nature, making people more susceptible to vulnerabilities. Innovations in this field can open the door to manipulation, as they expose the limitations

of human capabilities. On the other hand, awareness of one's own weaknesses and problems motivates people to address them to avoid negative consequences, such as loss of employment or social status. This requires lifestyle adjustments and the development of new ways of interacting with AI. It is essential to recognise that AI is a distinct type of technology, and anthropomorphising it, as well as equating it with other types of technology, is unacceptable. People have not yet developed ways of socially interacting with AI (Brooks B., 2024). Specific methods for describing and interacting with AI must be developed that differ from the ways of interacting with people and other types of technology.

Conclusion. Not only should artificial intelligence have limitations on its actions to prevent harm to humans, but humans, for example, when instructing artificial intelligence to commit a crime, should also bear responsibility for it. AI is a tool, but one so complex that it makes sense to consider responsibility not only to humanity but also to the AI itself.

The concepts of morality and ethics should not be used to describe principles integrated into AI. It is more appropriate to develop protocols for interaction with people, similar to treatment protocols in medicine, which consistently and thoroughly prescribe the sequence of actions and as many variations as possible. These protocols should take into account the safety, benefits, priorities, and individual needs of people. They should contain general ethical provisions; a definition of the ethical rule to be applied; methods for identifying (diagnosing) a moral problem, assessing the risk of complications or negative consequences in the event of ignoring the problem or its improper resolution; conditions under which the AI assumes responsibility for solving the problem (intervenes); options for solving the problem, a set duration for monitoring the consequences of actions taken and, if necessary, behavioral adjustments; conditions for continuing the search for a solution to the moral problem or terminating the intervention.

Humanity constantly accumulates and loses knowledge and skills, some of which become obsolete over time. The loss of morality is tantamount to the loss of human essence. Delegating some decisions to artificial intelligence does not absolve one of responsibility and ethical principles – only the scope of their application changes. Moral choice is a human choice and a human responsibility. However, if AI ever achieves a level of consciousness sufficient to make ethical decisions, its development in this area should not be hindered. At the same time, situations involving human life and well-being where AI is forced to make decisions should be avoided.

AI is a masterpiece of human thought and a new stage in knowledge, but how it will be used and how its potential will be realised depends entirely on humans, even if its intellectual capabilities surpass those of humans. The intellectual superiority of artificial intelligence will either open up new space for the development of human capabilities or destroy humanity. In this respect, it is similar to most technological or cultural innovations, the thoughtless exploitation of which is destructive to both society as a whole and the individual.

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PHYSICS

TIME TRAVEL IS FEASIBLE ON EARTH AS WELL?¹

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Abstract

The article proves that the version of the special relativity theory (SRT) that is taught in all physics textbooks is incorrect, since the relativistic formulas obtained in it are incorrect and they are incorrectly explained using the incorrect principle of not exceeding the speed of light. These formulas also lead to incorrect conclusions about the physical unreality of imaginary numbers and the existence in nature of only our visible universe.

A corrected version of the SRT is presented and it is explained that the argument 'speed' in the corrected relativistic formulas is, in accordance with Newton's first law, the fourth spatial dimension². The principle of the physical reality of imaginary numbers is experimentally proven, which refutes the principle of not exceeding the speed of light. It is shown that the SRT, on the one hand, and radio engineering, electrical engineering and computer engineering, on the other hand, mutually refute each other. It is explained that in nature, in addition to our visible universe, there are many mutually invisible, since they are in different dimensions, universes and anti-universes, which are dark matter and dark energy. This explains the well-known properties of dark matter and dark energy - their invisibility and the absence of corpuscular content. Therefore no studies at the Large Hadron Collider can explain the phenomena of dark matter and dark energy.

It is explained also that in the anti-universes of such an invisible Multiverse there is anti-matter and anti-time. Therefore, time travel is possible in it. Time travel is also available to people on Earth.

Keywords: special relativity theory, relativistic formulas, Multiverse, anti-universe, antimatter, anti-time, arrow of time, internal time, external time, time zones of Earth, time travels.

1. Introduction

The 20th century in physics was rich in new interesting scientific ideas. But some of them, although they were called theories, have not yet received experimental confirmation. And one of them is the special relativity theory (SRT) [1]-[3], which was nominated for the Nobel Prize 66 times. However, due to the lack of experimental confirmation, she never received it. And the Nobel Committee turned out to be right, since in the 21st century, its indisputable experimental refutations were published. Nevertheless, this version of SRT is now studied in all physics textbooks used in the educational process even in the most prestigious universities.

2. The version of SRT taught in all physics textbooks is incorrect

The generally accepted version of SRT is incorrect because the relativistic formulas obtained by its creators – Joseph Larmor [4], Nobel laureate Hendrik Anton Lorentz³ [5], Jules Henri Poincaré [6], Nobel laureate Albert Einstein⁴ [7] and other outstanding scientists – are incorrect:

$$m = m_0 / \sqrt{1 - \left(\frac{v}{c}\right)^2} \quad (1)$$

$$\Delta t = \Delta t_0 \sqrt{1 - \left(\frac{v}{c}\right)^2} \quad (2)$$

¹ This is corrected reprint of the article "Antonov A. A. 2025. Dark matter and dark energy are mutually invisible universes and anti-universes of the hidden Multiverse. German International Journal of Modern Science № 113."

² Not to be confused with the fourth dimension in four-dimensional space-time (Minkowski space).

³ Who received his Nobel Prize in 1902 for explaining the Zeeman effect.

⁴ Who received his Nobel Prize in 1921 for studying the photoelectric effect.

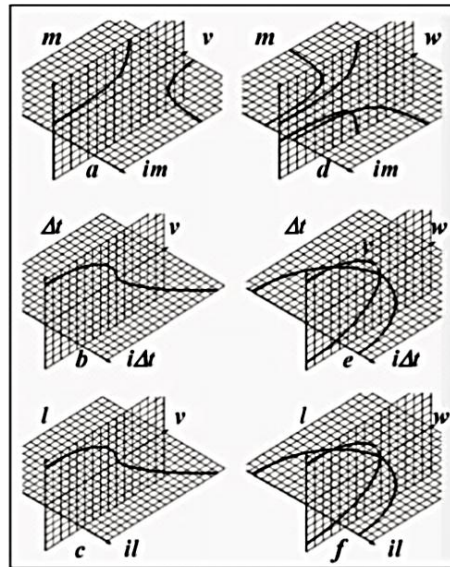


Fig 1. Graphs of functions $m(v)$, $\Delta t(v)$, $l(v)$, corresponding to the existing and corrected versions of SRT in the subluminal $v < c$ and hyperluminal $v > c$ ranges

$$l = l_0 \sqrt{1 - \left(\frac{v}{c}\right)^2} \quad (3)$$

where m_0 is the rest mass of a moving body (e.g., an elementary particle);

m is the relativistic mass of the moving body;

Δt_0 is the rest time of the moving body;

Δt is the relativistic time of the moving body;

l_0 is the rest length of the moving body;

l is the relativistic length of the moving body;

v is the speed of a moving body;

c is the speed of light.

Moreover the creators of SRT could not even explain these formulas. And there fore much of what they did later was done incorrectly:

- First, they did not understand that the velocity v in these formulas, in accordance with Newton's first law, is the fourth spatial dimension, in addition to length, width, and height. Therefore, relativistic formulas had to be explained not only in the sublight $v < c$ range, but also in the hyperlight $v > c$ range. However, this was not done.

- Second, not understanding the physical meaning of the imaginary values of the quantities $m(v)$, (v) , $l(v)$ in the hyperlight $v > c$ range of speeds, the authors of SRT, in order not to explain their relativistic formulas in this range, introduced into SRT a postulate called the principle of not exceeding the speed of light. And based on this postulate, it is now sometimes even claimed⁵ that Albert Einstein understood that nothing in the Universe can move faster than the speed of light. And that the speed of light is not just a number, but a physical limit. The same as, for example, absolute zero at a temperature of minus 273.15 degrees Celsius.

- Thirdly, it turned out that formula (1) in the hyperlight $v > c$ range corresponds to a physically unstable process that cannot exist in nature at all;

- Fourthly, in the 21st century, despite the fact that the attempt to disprove the SRT by the OPERA experiment [8] at the Large Hadron Collider was unsuccessful, it was nevertheless experimentally proven that imaginary numbers are physically real [9]-[20], and therefore the principle of not exceeding the speed of light and the SRT itself are incorrect [21]-[49].

Therefore, the conclusions made in the generally accepted version of the SRT from these incorrect formulas using the incorrect principle of not exceeding the speed of light are also incorrect:

- about the existence of our only visible universe in nature;
- about the physical unreality of imaginary numbers.

And, ultimately, this incorrect version of the SRT, as a result of the struggle for survival, instead of being corrected in the future, being canonised – a conviction formed in the community of relativistic physicists and in public opinion about its infallibility, about the inadmissibility of its criticism and any subsequent corrections. Therefore, for example, in the USSR, criticism of the SRT was prohibited three times: in 1934 by a resolution of the Central Committee of the All-Union Communist Party (Bolsheviks) on the discussion of relativity, in 1942 by a resolution of the Presidium of the Academy of Sciences of the Soviet Union on the theory of relativity, and in 1964 by a secret resolution of the Presidium of the Academy of Sciences of the Soviet Union, which prohibited any criticism of Albert Einstein's theory. This ban has not been lifted to this day.

And prohibiting criticism of scientific theories is not a new phenomenon. Therefore Nicolaus Copernicus, who spent 40 years in the 16th century developing his heliocentric model of the universe, prudently chose to publish his theory 'On the Revolutions of the Celestial Spheres,' which refuted Claudius Ptolemy's geocentric model, after his death, so as not to fall foul of

⁵ However, this unproven statement is incorrect, as it is refuted by the experimentally confirmed conclusion about the existence of the hidden Multiverse, in which different values

of the fourth spatial dimension v correspond to numerous mutually invisible universes and antiuniverses [85]-[98].

Other proofs of the physical reality of imaginary numbers have also been published [51]-[54].

4. Corrected version of SRT; invisible universes and anti-universes, hidden Multiverse

Since, as has just been proven, imaginary numbers are physically real, the relativistic formulas of SRT, taking this circumstance into account, need to be explained in full, since the creators of this theory explained them only in the range of sublight speeds $v < c$, in which the physical values m , Δt and l took values measurable by real numbers. But in the range of hyperlight speeds $v > c$, these values m , Δt and l already took

values measurable by open [55] Scipione Del Ferro, Niccolò Fontana Tartaglia, Gerolamo Cardano, Lodovico Ferrari and Raffaele Bombelli 400 years before the creation of SRT as imaginary numbers, the physical meaning of which, however, was incomprehensible to them and was not explained. And perhaps even earlier than them, imaginary numbers were discovered by Paolo Valmes [56], who was burned alive at the stake for this by order of the inquisitor Tomás de Torquemada. Even Isaac Newton, in order to avoid trouble, preferred not to use imaginary numbers at that time⁸.

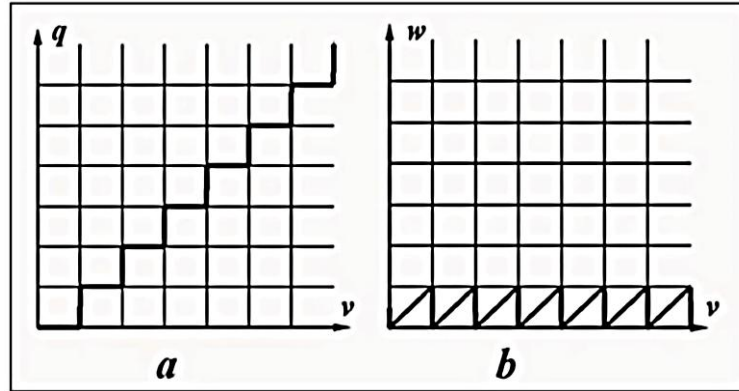


Fig. 3. Graphs of functions $q(v)$ and $w(v)$, illustrating the meaning of the 'floor' function of discrete mathematics

However, in order to explain the physical meaning of imaginary numbers, relativistic formulas must first be corrected so that they correspond to physically feasible processes. To do this, relativistic formulas (1)-(3) in the range $v > c$ must be such that the graphs of the functions $m(v)$, $\Delta t(v)$, $l(v)$ (Fig. 1d,e,f) are similar to the graphs of the same functions $m(v)$, $\Delta t(v)$, $l(v)$ 1a,b,c) in the range $v < c$. To do this, we need to introduce the function⁹ i^q into formulas (1)-(3)

$$m(q) = m_0 i_1^q / \sqrt{1 - (\frac{v}{c} - q)^2} \quad (4)$$

$$\Delta t(q) = \Delta t_0 i_1^q \sqrt{1 - (\frac{v}{c} - q)^2} \quad (5)$$

$$l(q) = l_0 i_1^q \sqrt{1 - (\frac{v}{c} - q)^2} \quad (6)$$

where $q(v) = \lfloor v/c \rfloor$ – the 'floor' function of discrete mathematics from the argument v/c (its graph is shown in Fig. 3a), which is the fourth spatial dimension;

$w = v - qc$ – local velocity in all universes (its graph is shown in Fig. 3b).

This function i^q in formulas (4)-(6), which defines the essence of each universe, for integer values $q(v)$, equal to 0,1,2,3,4,5, takes the values +1, +i, -1, -i, +1, +i, ... etc. And the value $q(v) = 0$ in formulas (1)-(3) for

the sublight speed range $v < c$ corresponds (since $i^0 = 1$) to our visible universe, which we will call the tardion¹⁰ universe for the sake of clarity. The value $q(v) = 1$ in the hyperlight speed range $2c > v > c$ corresponds (since $i^1 = i$) to some other invisible universe, since it is beyond the event horizon. For clarity, we will therefore call it the tachyonic¹¹ universe. Then the value $q(v) = 2$ in the speed range $3c > v > 2c$ will correspond to (since $i^2 = -1$) an invisible tardion anti-universe, and the value $q(v) = 3$ in the speed range $4c > v > 3c$ will correspond to (since $i^3 = -i$) an invisible tachyonic anti-universe, the value $q(v) = 4$ in the speed range $5c > v > 4c$ will correspond (since $i^4 = +1$) to another (and therefore also invisible) tardionic universe, the value $q(v) = 5$ in the speed range $6c > v > 5c$ will correspond (since $i^5 = +i$) to another tachyon universe. And so on.

That is, according to formulas (4)-(6), there is not one visible universe, as claimed in the generally accepted version of SRT, but a multitude of mutually invisible other universes and anti-universes, forming a Multiverse, which we will therefore call hidden. Such a hidden Multiverse, whose structure is helical, is shown in Fig. 4. And in this structure of the hidden Multiverse, the distribution of material content in each three-dimensional parallel universe and anti-universe will

⁸ And his friend William Whiston, in the atmosphere of the omnipotence of the Inquisition, was stripped of his professorship and expelled from Oxford University for some of his careless re-marks.

⁹ However, the i^q function has the disadvantage that, in the theory of complex variable functions, it is defined only for integer values 0,1,2,3,4,5, ... of the argument q . Therefore, considering that for integer values of the argument q the same values as the i^q function are taken by Euler's formula $e^{iq\pi/2} = \cos(q\pi/2) + i\sin(q\pi/2)$, the author proposes the formula

$i^q = \cos(q\pi/2) + i\sin(q\pi/2)$ for non-integer values of the argument q . The latter formula has an important dignity, it introduces a mathematical operation into complex number mathematics that was previously absent, namely, raising imaginary numbers to non-integer powers.

¹⁰ Tardyon universe is a term used by Isaak Asimov in his short story 'Take a Match'.

¹¹ Tachyon universe is a term used by Isaak Asimov in his short story 'Take a Match'.

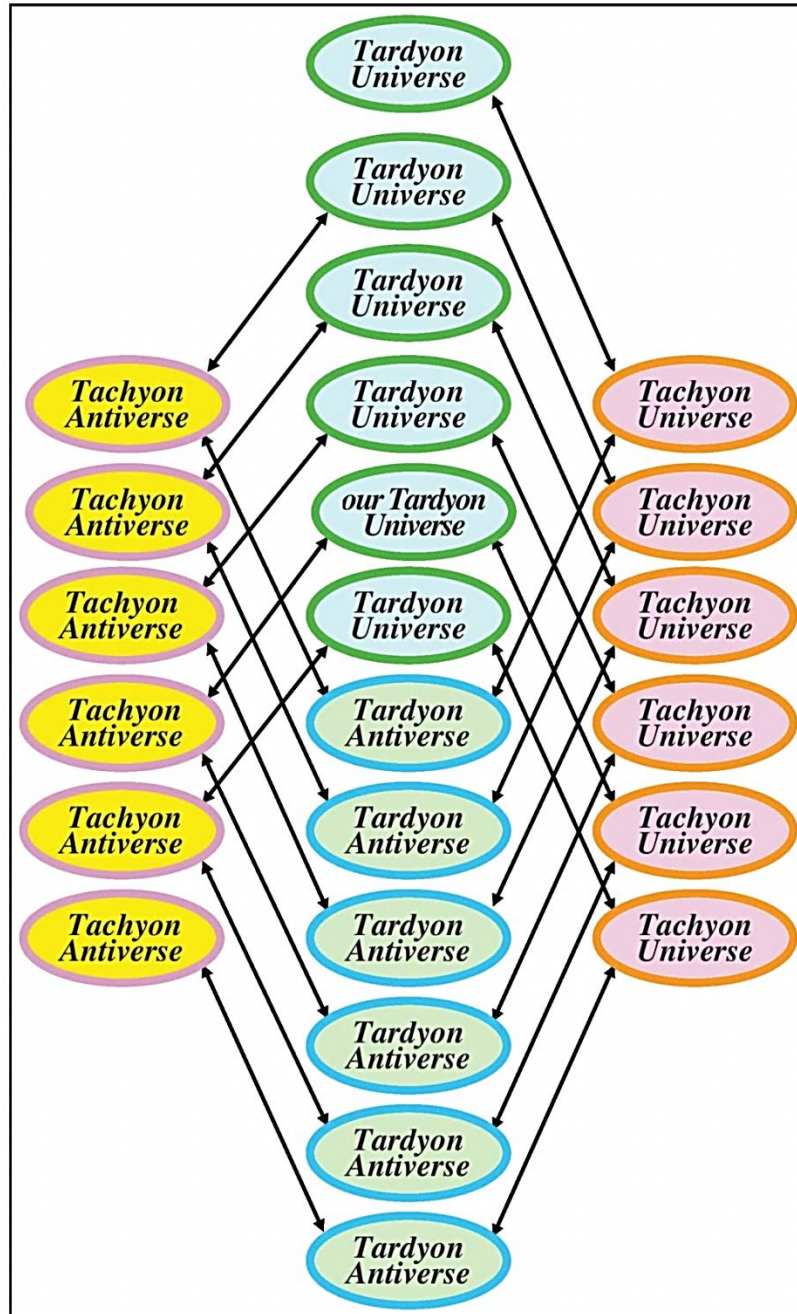


Fig. 4. Structure of the hidden Multiverse corresponding to the principle of physical reality of complex numbers

be determined by its function $f_q(x, y, z)$, and the value iq will be the coordinate of these universes¹². That is, the hidden Multiverse will be described by the formula $f_q(x, y, z) + iq$.

5. Analysis of data obtained by the WMAP and Planck spacecraft

But having proven the existence of mutually invisible parallel¹³ universes and anti-universes, necessary to find out how they are placed in the hidden Multiverse. Or, in other words, what is the structure of this hidden Multiverse? It is also necessary to understand what dark matter and dark energy are, so named because of their incomprehensibility, since no chemical elements have been found in them, and also because

they do not absorb, emit, reflect or refract any electromagnetic radiation, and are therefore invisible.

Moreover, dark matter and dark energy account for more than 95% of all mass-energy in the cosmos. More precisely, according to data obtained by the WMAP spacecraft [57], the mass-energy of our visible universe (actually a hidden Multiverse) consists of 4.6% baryonic matter, 22.4% dark matter, and 73.0% dark energy. And according to more recent data obtained by the Planck spacecraft [58], the entire universe (again, in fact, the entire hidden Multiverse) consists of 4.9% baryonic matter, 26.8% dark matter, and 68.3% dark energy.

¹² Thus proving that the fourth spatial dimension iq , as stated in section 2, is a physically real variable quantity

¹³ Since they do not intersect

Therefore, naturally, the reliability of other knowledge in modern physics, which is unable to explain the phenomena of dark matter and dark energy, is questionable. And since it has been proven beyond doubt that nature does not consist of a single universe, but a Multiverse, then, in addition to the still unsuccessful search in the microcosm for the nature of dark matter and dark energy phenomena at the Large Hadron Collider, it is necessary to begin searching for their explanation in the macrocosm of our hidden Multiverse. After all, Albert Einstein himself wrote: *'It is meaningless to keep doing the same thing and expect different results'*. The ancient Chinese philosopher Confucius¹⁴ said the same thing: *'The most difficult thing is to find a black cat in a dark room, especially if it is not there'*.

The search for a solution to this problem in the hidden Multiverse allows us to assume that [59]-[72]:

- dark matter and dark energy are most likely the rest, besides our visible universe, the tachyon and tachyon universes and anti-universes of our hidden Multiverse, which are invisible to us because they are in other dimensions;
- and since the universes and anti-universes of dark matter and dark energy are actually outside our visible universe, they manifest themselves in it only as phenomena (presumably in the form of gravitational shadows) generated by the existence of other invisible parallel universes and anti-universes of the hidden Multiverse¹⁵;
- dark matter is a phenomenon caused by the existence of invisible parallel universes and anti-universes in the hidden Multiverse neighbouring our visible universe.
- dark energy is a phenomenon generated by the existence of other universes besides our visible universe and its neighbouring invisible universes and anti-universes, other invisible parallel universes and anti-universes of the hidden Multiverse.

Therefore, dark matter and dark energy have no corpuscular content¹⁶. And they will never be detected at the Large Hadron Collider.

This explanation of the phenomena of dark matter and dark energy also provides information about the structure of the hidden Multiverse. Indeed, given that the mutually invisible universes and anti-universes of the hidden Multiverse are connected to each other by numerous portals through which they exchange their material contents, it can be argued that over billions of years of their existence, in accordance with the law of communicating vessels, their mass-energy has practically completely equalised. And then:

- according to experimental data obtained by the WMAP spacecraft, the entire hidden Multiverse consists of $100\% / 4.6\% = 21.8$ parallel universes, and according to data obtained by the Planck spacecraft, it consists of $100\% / 4.9\% = 20.4$ parallel universes;
- dark matter, according to experimental data obtained by the WMAP spacecraft, consists of $22.4\% / 4.6\% = 4.9$ parallel universes, and according to data obtained by the Planck spacecraft, consists of $26.8\% / 4.9\% = 5.5$ parallel universes;
- according to experimental data obtained by the WMAP spacecraft, dark energy consists of $73.0\% / 4.6\% = 15.9$ parallel universes, and according to data obtained by the Planck spacecraft, it consists of $8.3\% / 4.9\% = 13.9$ parallel universes.

6. Corrected version of SRT, explanation of the phenomena of dark matter and dark energy

As can be seen, the experimental data obtained by the WMAP and Planck spacecraft did not confirm the above conclusions about the structure of the hidden Multiverse, since our visible universe in this structure has not two neighbouring invisible parallel universes – one tachyon universe and one tachyon anti-universe – but five or six.

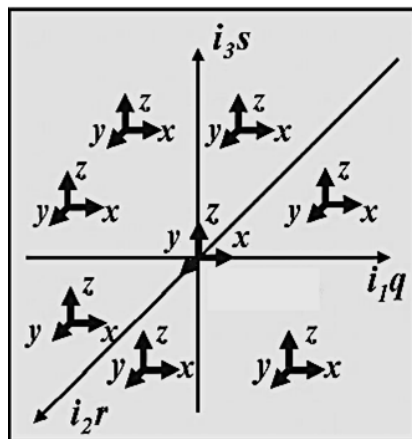


Fig. 5. Six-dimensional space of the hidden Multiverse, where q, r, s are the coordinates of invisible parallel universes, and x, y, z are the coordinates of the matter content in each parallel universe

¹⁴ Confucius was an ancient Chinese philosopher and statesman who lived more than two thousand years ago and remains the most famous Chinese person to this day. For a long time, Confucianism was as important in China as Buddhism. It forms the basis of modern state ideology.

¹⁵ Similarly, for example, you may search unsuccessfully for a ringing telephone in the room you are in, when it is actually in the next room.

¹⁶ Like shadows on a sunny day.

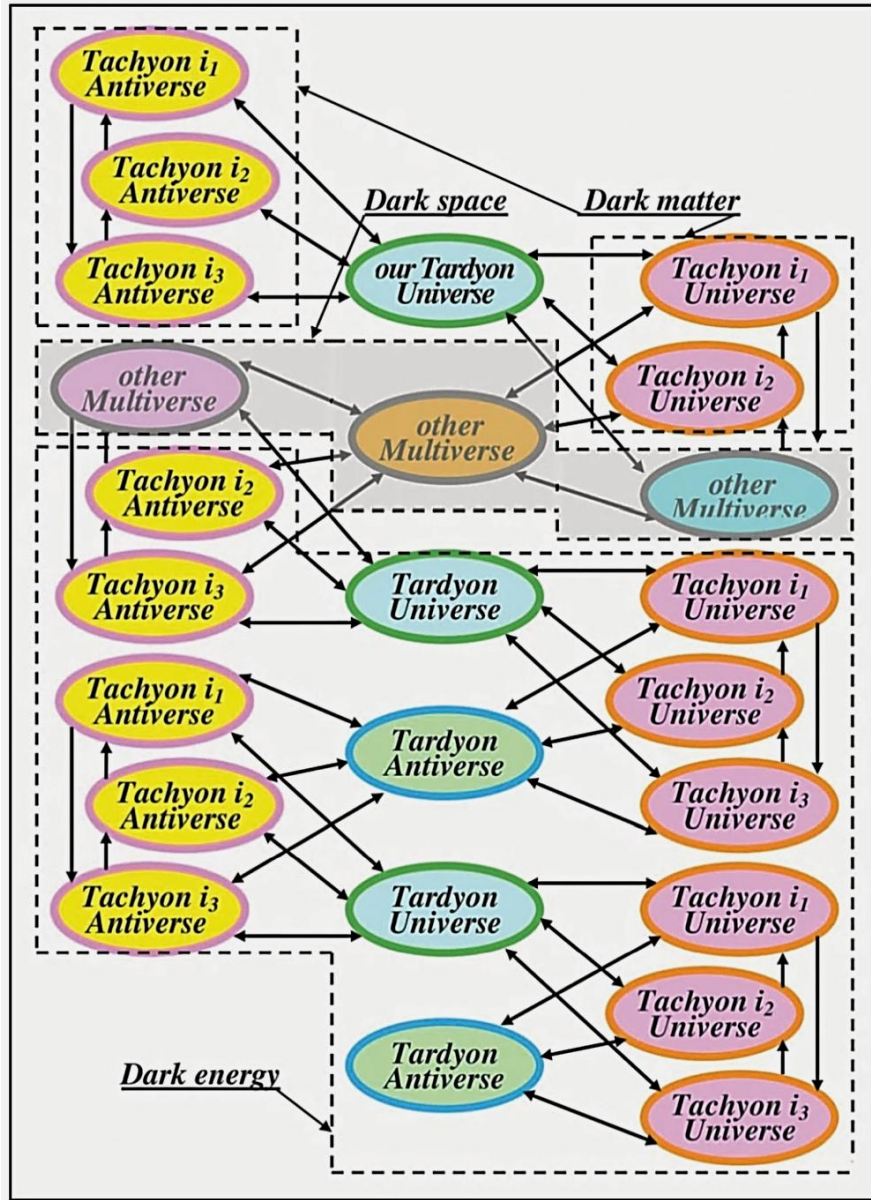


Fig. 6. Possible quaternion structure of the hidden Multiverse containing twenty-two parallel universes, including six invisible universes adjacent to our visible universe

$$m(q, r, s) = \frac{m_0 i_1^q i_2^r i_3^s}{\sqrt{1 - [\frac{v}{c} - (q + r + s)]^2}} \quad (7)$$

$$\Delta t(q, r, s) = \Delta t_0 i_1^q i_2^r i_3^s \sqrt{1 - [\frac{v}{c} - (q + r + s)]^2} \quad (8)$$

$$l(q, r, s) = l_0 i_1^q i_2^r i_3^s \sqrt{1 - [\frac{v}{c} - (q + r + s)]^2} \quad (9)$$

where $q(v) = [v_q/c]$ – the ‘floor’ function of discrete mathematics from the argument v_q/c , which is one of the orthogonal coordinates q of the fourth spatial dimension $\mathbf{v}$;

$r(v) = [v_r/c]$ – the ‘floor’ function of discrete mathematics from the argument v_r/c , which is another orthogonal coordinate r of the fourth spatial dimension $\mathbf{v}$;

$s(v) = [v_s/c]$ – the ‘floor’ function of discrete mathematics from the argument v_s/c , v_q/c , which is

one more orthogonal coordinate s of the fourth spatial dimension $\mathbf{v}$;

v_q, v_r, v_s – projections of the velocity vector $\mathbf{v}$ onto the orthogonal coordinates q, r, s (see Fig. 5).

Consequently, the space of such a hidden Multiverse will be six-dimensional (see Fig. 5). And its structure will correspond to the quaternions $\sigma + i_1\omega_1 + i_2\omega_2 + i_3\omega_3$, i.e. hypercomplex numbers [82] containing precisely three imaginary units i_1, i_2, i_3 , which are related to each other by the following relations

$$i_1^2 = i_2^2 = i_3^2 = -1 \quad (10)$$

$$i_1 i_2 i_3 = i_2 i_3 i_1 = i_3 i_1 i_2 = -1 \quad (11)$$

$$i_1 i_3 i_2 = i_2 i_1 i_3 = i_3 i_2 i_1 = 1 \quad (12)$$

In such a quaternion structure of the hidden Multiverse [83], [84], unlike its structure considered earlier (in Fig. 4), the distribution of material content in each three-dimensional parallel universe will be determined by a function $f_{q,r,s}(x, y, z)$, and the coordinates of these universes will be determined by the values $i_1 q, i_2 r$ и $i_3 s$. That is, the hidden Multiverse will be described by the formula $f_{q,r,s}(x, y, z) + i_1 q + i_2 r + i_3 s$. This is exactly what Lisa Randall predicted: *'We could be living in a three-dimensional pocket of higher dimensional space'*.

And from formulas (7)-(9) it follows that such a hidden Multiverse has a helical structure. In this case, it is possible to move from a tardion universe to a tardion antiuniverse and from a tardion antiuniverse to a tardion universe in different ways, but not in an arbitrary way, but only in such a way (see Fig. 6) that the function i^q will successively take the values $+1, +i_1 \oplus +i_2 \oplus +i_3, -1, -i_1 \oplus -i_2 \oplus -i_3, +1, \dots$ and so on, where $\oplus$ is the symbol of the logical operation of discrete mathematics 'exclusive OR'. In this case, different trajectories of movement from one universe (or antiuniverse) to another can differ only due to the replacement of some tachyon universes from i_1, i_2, i_3 with others and some tachyon antiuniverses from i_1, i_2, i_3 with others. The tachyon antiuniverses i_1, i_2, i_3 are also located parallel to each other for the same reasons. And therefore, in the hidden Multiverse, when moving from any tardion universe to a tardion antiuniverse and then to another tardion universe, parallel universes and antiuniverses must alternate in the following sequence – 'tardion universe', 'one of the tachyon universes', 'tardion antiuniverse', 'one of the tachyon antiuniverses', 'tardion universe', 'one of the tachyon universes', etc.

One of the simplest for such possible quaternion structures of the hidden Multiverse is shown in Fig. 6. It differs from the structure shown in Fig. 4 in that it contains several parallel tachyon universes and antiuniverses corresponding to the three imaginary units i_1, i_2, i_3 . Another difference is the presence in such a Multiverse structure not only of bidirectional portals corresponding to formula (7) and marked with double-headed arrows, but also of unidirectional portals¹⁷, corresponding to formulas (8) and (9) and marked with single-headed arrows.

Moreover, naturally, the movement from our tardion universe to the tardion antiuniverse through some

tachyon universe – for example, i_1 – does not necessarily have to proceed further through the tachyon antiuniverse i_1 . It can proceed further through the tachyon antiuniverses i_2 and i_3 . The same reservation applies to the situation if the movement from the tardion universe to the tardion antiuniverse begins through the tachyon universes i_2 and i_3 . All these transitions are shown in Fig. 6. Moreover, since the data obtained by the WMAP and Planck spacecraft correspond to open helical structures of our hidden Multiverse, united through the corresponding portals with other Multiverses, then all of them together form the Hyperuniverse.

7. How to see invisible universes and anti-universes?

But to verify that these invisible universes really exist, we need an appropriate experiment that allows us to see them [85]-[98]. And to understand what this experiment might be like, we need to remember that in formulas (7)-(9), the parameters q, r, s are orthogonal coordinates of the fourth spatial dimension v , in which mutually invisible parallel universes somehow drift relative to each other. Therefore, they touch each other and even slightly immerse into each other, forming corresponding transitions through which their material contents are exchanged. These transitions are usually called portals [99],[100]. The entrances to them appear to be, at least, some of the anomalous zones, of which there are more than two hundred thousand on Earth. [101]-[104].

And since in other universes the constellations in the sky inevitably differ from the constellations in our earthly sky, when travelling through a portal from Earth to a neighbouring universe or anti-universe, the map of the starry sky in the portal will gradually transform into a map of the starry sky of that neighbouring universe or anti-universe. And if a telescope is placed in such a portal (or at least at its entrance in the anomalous zone), then by comparing the position of the stars in the sky in the portal and outside the portal, changes in the position of the stars can be detected. And if these differences turn out to be too small, then the telescope will have to be moved deeper into the portal. After all, Sir Arthur Stanley Eddington moved his telescope much further for his famous experiment in the early 20th century – from England to the island of Principe in the Atlantic Ocean [105].

These other constellations in the starry sky in the portals will serve as experimental proof of the existence of invisible universes and anti-universes outside the portals. The corresponding experiments (Fig. 7) are very inexpensive

¹⁷ Why in such portals movement is possible only in one direction - from the entrance to the exit - is difficult for us, living in a space in which movement in nature is possible in any direction, to imagine. The processes that determine the possibility of such movement in nature are yet to be understood.

But for visitors who find themselves in such one-way portals, they are more dangerous than two-way portals, since it is impossible to return from them to your universe. Although in the metro with one-way movement on escalators we still encounter. But the metro is not nature.

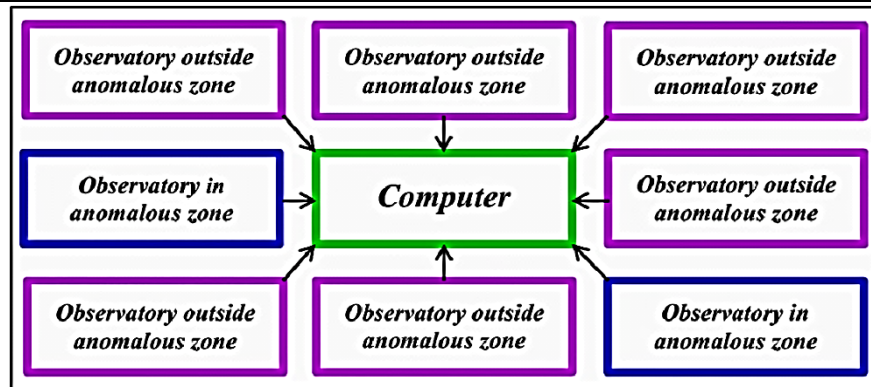


Fig. 7. Scheme of an astronomical experiment to detect invisible universes

and easy to implement. Moreover, some observatories are already located in anomalous zones. For example, the Main Astronomical Observatory of the National Academy of Sciences of Ukraine is located 12 km from the centre of its capital, Kiev, in the Holosivskyi Forest.

8. Antimatter and anti-time, external and internal time

Having convinced ourselves that the existence of the hidden Multiverse can be proven experimentally, let us continue to extract new knowledge from the corrected version of SRT.

First, the structure of the hidden Multiverse already allows us to explain a problem that is currently inexplicable within the framework of physics textbooks: where is antimatter located [106]? It is clear that it cannot be found in our visible universe, since its annihilation with matter would cause our universe to cease to exist. But the fact that antimatter does exist has been proven experimentally. In 1995, a sensational result was obtained at CERN – scientists managed to obtain nine atoms of antihydrogen, which existed for about forty billionths of a second. And just one gram of such antihydrogen would cost 662.5 trillion (i.e. a thousand billion) dollars. Thus, the existence of antimatter has been experimentally proven.

This experiment can also be considered proof that, in accordance with formulas (7)-(9), antimatter can exist in nature, but only in the invisible tardion and tachyon anti-universes of the hidden Multiverse and Hyperuniverse. (see Fig. 6), since they are the antipodes of invisible tardion and tachyon universes. Matter/antimatter pairs can also exist in tachyon universes/antiuniverses. Moreover, in these invisible tardion and tachyon antiuniverses, anti-time and anti-space also exist [107]-[116].

Secondly, the existence in the hidden Multiverse of not only tardion and tachyon universes, but also anti-universes, makes it possible to travel not only in space, but also in time [107]-[127]. This refutes the claim of physicists who, although they recognise the hypothetical possibility of time travel in certain exotic situations in special¹⁸ and general¹⁹ relativity and in quantum physics²⁰, but deny the possibility of human time travel

even in the distant future. Because in the generally accepted version of STR studied in physics textbooks, the existence of anti-universes is also denied.

That is why the concept of the “arrow of time” [128], proposed at the beginning of the 20th century by Sir Arthur Stanley Eddington, even appeared in physics. Here is what Stephen William Hawking [129] wrote on this subject: *‘In everyday life, there is a huge difference between moving forward and backward in time. Imagine that a cup of water falls off the table and breaks into pieces. If you film this fall, it will be immediately clear when watching the film whether the film is being played forwards or backwards. If it is being played backwards, we will see the shards lying on the floor suddenly come together and, forming a whole cup, jump back onto the table. And you can say that the film was being played backwards, because in everyday life this does not happen. Otherwise, all the pottery factories would have to be closed down.’*

However, the existence of anti-time in the hidden Multiverse makes the use of the concept of ‘arrow of time’ unnecessary.

And finally, thirdly, it is easy to notice that in all the relativistic formulas (1)-(3); (4)-(6); (7)-(9) mentioned in the article, in addition to the functional dependencies of the quantities m , Δt , l on the argument v , there is another functional dependence – the quantity Δt on the argument l

$$\Delta t = \Delta t_0 l / l_0 \quad (13)$$

Thus, it turns out that in nature, there exist not only the relativistic dependences of physical quantities m , Δt , and l on velocity v , already identified and studied in the generally accepted version of special relativity, but also another dependence of external time Δt , generated by the Earth's rotation around its axis, on the displacement of a material body l (for example, an airplane), perpendicular to time zones. And this external time differs from the internal (or, in other words, biological) time used by people, which cannot flow backwards, and people within it cannot return to their childhood. External time, however, can flow both into the future and into the past, since airplanes can cross time zones in both western and eastern directions.

Moreover, unlike internal time, which always and everywhere flows at the same speed, this external time,

¹⁸ For example, in the ‘twin paradox’

¹⁹ For example, in the region of ultra-high gravity near the event horizon of a black hole

²⁰ For example, as a result of teleportation of physical object instead of information

measured by time zones, can flow at different speeds, depending on the speed of the aircraft and the size of the time zones.

Therefore:

- at the equator 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 0^\circ / 24 = 1700 \text{ km}$;
- at the latitude of Santiago 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 33.45^\circ / 24 = 1426 \text{ km}$;
- at the latitude of Buenos Aires 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 34.60^\circ / 24 = 1427 \text{ km}$;
- at the latitude of Melbourne 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 37.82^\circ / 24 = 1358 \text{ km}$;
- at the latitude of New York 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 40.72^\circ / 24 = 1269 \text{ km}$;
- at the latitude of Reykjavik 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 64.15^\circ / 24 = 734 \text{ km}$;
- at the latitude of Murmansk 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 69^\circ / 24 = 601 \text{ km}$;
- at the latitude of Kirkenes 1 time zone is equal to $\Delta l = 40075 \text{ km} \times \cos 69.73^\circ / 24 = 599 \text{ km}$.

Then the distance of 1 time zone an airplane with a speed of, for example, 800 km per hour, will fly:

- at the equator in $\Delta t = 1700 \text{ km} / 800 \text{ km per hour} = 2.125$ hours of internal (biological) human time;
- at the latitude of Santiago in $\Delta t = 1426 / 800 \text{ km per hour} = 1.783$ hours of internal (biological) human time;
- at the latitude of Buenos Aires in $\Delta t = 1427 / 800 \text{ km per hour} = 1.784$ hours of internal (biological) human time;
- at the latitude of New York in $\Delta t = 1586 / 800 \text{ km per hour} = 1.983$ hours of internal (biological) human time;
- at the latitude of Reykjavik for $\Delta t = 734 / 800 \text{ km per hour} = 0.918$ hours of internal (biological) human time;
- at the latitude of Murmansk for $\Delta t = 601 / 800 \text{ km per hour} = 0.751$ hours of internal (biological) human time;
- at the latitude of Kirkenes for $\Delta t = 599 / 800 \text{ km per hour} = 0.749$ hours of internal (biological) human time.

This happens because external time is the time outside the plane, determined by processes in the external environment, and internal time is the time measured by the watches of passengers and crew. Therefore, after the plane lands, passengers have to change their watches to local internal time. And, as you can see, in order to travel to the past or the future, the plane's flight during its round-the-world trip must take place around the nearest pole close enough to it (since the time zones there are smaller).

9. How to verify the feasibility of time travelling to the past and future?

From the calculations given in the previous section, it follows that if an airplane crosses, for example, one time zone on Earth in an external time exactly equal to one hour, then the watches of the passengers and crew of the airplane after landing will show other local time - greater, equal, or less than one hour. This means that after the plane lands, passengers and crew of the plane will need to set their watches forward or back. Consequently, as a result of the flight, they will actually

move not only in space, but also into their biological future or past time.

And with such a flight, the concept of an "arrow of time" [127] will be refuted. Thus, people on Earth are already traveling through time, despite physicists' belief that it is impossible. Moreover, they are simultaneously traveling through space. But this makes such time travel unnecessary. And therefore unused.

However, presumably people on Earth can travel through time. If, as a result of such a journey, the aeroplane returns to the same aerodrome from which it departed. In particular, for example, as a result of a round-the-world trip, since as a result of flying in one direction and the other along the same route, time travel will not work. But if you fly in the same direction all the time – to the West or to the East – then during such a long flight you can get time travel. And such a journey can be very useful [117]-[126]. Especially if it turns out that it is physically possible to talk on the phone with yourself in the past or future.

Such time travel, of course, will be expensive, but sometimes it can still be accomplished (if necessary), since the planes and airfields needed for this already exist. However, even in this case, not everything is clear. It is not clear where the plane will land as a result of such time travel. Although he usually flies to the same airfield from which he took off. And now planes almost always return to the same airfield from which they took off. So what's the problem? The problem is that aeroplanes have not yet made round-the-world trips. And therefore it is unknown what complications may arise.

Therefore, for now we will try to solve this problem speculatively. Let's assume that two planes take off from the same airfield at the same time. But one of them flew to the West, i.e. in the past time, and the other to the East, i.e. in the future tense. Therefore, one plane will land at the same airfield from which it took off almost a day earlier, and the other plane will land almost a day later. Does everything seem simple and clear?

Not at all. It is completely incomprehensible why two identical planes, simultaneously taking off from the same airfield and flying at the same speed over the same distance, will arrive at the same airfield at different times. Moreover, with a time difference of more than a day. This cannot be explained by any reference to different weather conditions due to different routes. So perhaps the reason is that our Earth is somehow more complex than a globe. And in order to understand this problem, such a round-the-world experimental flight will need to be actually carried out on at least one aircraft. After which the problem of time travel, most likely, can be solved.

10. Conclusion

Our visible world is largely unknown, which is confirmed by numerous scientific discoveries made over the past decades. But this visible world is immersed in a huge and almost completely unknown invisible world, which, however, some scientists do not want to recognize or study.

For example, relativistic physicists still refuse to acknowledge the physical reality of imaginary numbers, which experimentally proves that the generally

accepted version of SRT is incorrect. And they are not even bothered by the fact that if the generally accepted version of SRT were correct, then electrical engineering, radio engineering, computer engineering, and many other things would not exist. Even church bells would not ring, and swings would not swing in playgrounds [9]-[20], [51]-[54].

The generally accepted version of SRT is also incorrect due to the fact that in the incorrect relativistic formulas obtained in it, the fact that the speed v in them, in accordance with Newton's first law, is the fourth spatial dimension [117]-[126] is ignored. Moreover, unable to explain the physical meaning of imaginary numbers, the authors of the incorrect SRT introduced in it the incorrect principle of not exceeding the speed of light, which even prohibits the recognition of the existence of a fourth spatial dimension v in it. And thus they forbade physicists in the future from even guessing in the SRT about what they themselves had not guessed.

In addition, the incorrect conclusion made by the creators of this SRT from the incorrect principle of not exceeding the speed of light about the existence of only our visible universe in nature, has for almost 100 years now has made it impossible to explain the phenomena of dark matter and dark energy. Therefore, their explanations are forced to be sought only in the microcosm at the Large Hadron Collider. But they will never be found, because dark matter and dark energy actually are not objects in the microcosm, but are mutually invisible universes and anti-universes in a hidden Multiverse [59]-[72], the existence of which is denied by the generally accepted version of STR.

Finally, only the existence of a hidden Multiverse can explain where antimatter and tachyons [107]-[116] are located. But in the existing version of SRT, which recognizes the existence of only one our visible universe, this is impossible to do, since antimatter is located in the antiuniverses of the hidden Multiverse, and tachyons are located in its tachyon universes and anti-universes adjacent to our visible tardyon universes. And the existence of anti-time in antiuniverses allows us to assert that in the hidden Multiverse travel is possible not only in space, but also in time [117]-[126]. Moreover, time travel for people, denied by modern physics, is possible not only between universes and antiuniverses of the hidden Multiverse, but even on Earth.

Thus, the generally accepted version of the SRT [21]-[49], which is now studied in all physics textbooks, has made it impossible to explain many problems in physics that remain unexplained to this day. Nevertheless, these textbooks to this day are used in the educational process all over the world, even in the most prestigious universities. That is why they have been hindering the development of science for over 100 years. Although a corrected version of the SRT has already been created [73]-[84].

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PHYSIOLOGY OF ANIMALS

ПРИМЕНЕНИЕ УФ-ИЗЛУЧЕНИЯ ДЛЯ ОБЕЗЗАРАЖИВАНИЯ ВОЗДУХА В ИНКУБАТОРИЯХ И ВЫКОРМОЧНЫХ ПОМЕЩЕНИЯХ ТУТОВОГО ШЕЛКОПРЯДА (*BOMBYX MORI* L.)

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APPLICATION OF UV IRRADIATION FOR AIR DISINFECTION IN INCUBATORS AND REARING ROOMS OF THE MULBERRY SILKWORM (*BOMBYX MORI* L.)

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Аннотация

Экологизация шелководства требует отказа от химических дезинфектантов в пользу безопасных методов профилактики заболеваний тутового шелкопряда (*Bombyx mori* L.). Одним из перспективных решений является комбинированное использование УФ-излучения и ионизации воздуха. Эксперименты 2023–2025 гг. в Научно-исследовательском институте шелководства (Ташкент, Узбекистан) с гибридом «Навруз 3» подтвердили эффективность бактерицидных ламп ($\lambda=254$ нм, 90 Вт) и ионизаторов. УФ-обработка существенно снизила микробную нагрузку воздуха и яиц. Ключевые показатели: оживляемость - 99,0 % против 95,0 % (контроль); жизнеспособность гусениц - 86,5–90,1 % против 84,3 %; заболеваемость - 1,06–2,1 % против 3,1 %; вес одной гусеницы в V возрасте: 1,59–1,60 г против 1,42 г; масса шелковой оболочки: 0,365 г против 0,304 г; шелконосность: 22,9 % против 20,3 %. Комбинация УФ-излучения и ионизации — эффективный, экологически безопасный способ дезинфекции, улучшающий биологические и технологические показатели шелковопряда.

Abstract

The greening of sericulture requires the replacement of chemical disinfectants with safe methods for preventing diseases of the mulberry silkworm (*Bombyx mori* L.). One promising solution is the combined use of UV irradiation and air ionization. Experiments conducted in 2023–2025 at the Scientific Research Institute of Sericulture (Tashkent, Uzbekistan) using the hybrid "Navruz 3" confirmed the effectiveness of bactericidal lamps ($\lambda = 254$ nm, 90 W) and ionizers. UV treatment significantly reduced microbial contamination of the air and silkworm eggs. Key results: hatching rate – 99.0 % vs 95.0 % (control); larval survival – 86.5–90.1 % vs 84.3 %; disease incidence – 1.06–2.1 % vs 3.1 %; fifth-instar larval weight – 1.59–1.60 g vs 1.42 g; cocoon shell weight – 0.365 g vs 0.304 g; and shell ratio – 22.9 % vs 20.3 %. The combination of UV irradiation and air ionization proved to be an effective and environmentally safe disinfection method that improves the biological and technological performance of silkworm rearing.

Ключевые слова: ультрафиолетовая стерилизация; *Bombyx mori*; ионизация воздуха; выкормка шелкопряда; урожай коконов; профилактика заболеваний.

Keywords: ultraviolet sterilization; *Bombyx mori*; air ionization; silkworm rearing; cocoon yield; sustainable sericulture; disease prevention.

ВВЕДЕНИЕ

Развитие шелководства в мировом масштабе и достижение высоких, качественных урожаев коконов во многом зависят от профилактики заболеваний тутового шелкопряда (*Bombyx mori* L.). Ключевым фактором, определяющим здоровье и продуктивность популяций шелкопряда, является качество яиц (грены), используемых для инкубации и выкормки, а также стерильность условий в помещениях для содержания личинок. Санитарное состояние этих помещений напрямую влияет на выживаемость личинок и качество получаемых коконов. По объёму производства коконов лидирующие позиции в мире занимают Китайская Народная Республика (около 782 тыс. т), Индия (225 тыс. т) и Узбекистан (25,8 тыс. т) [1,2]. Эти страны признаны мировыми лидерами в области шелководства и формируют глобальные тенденции развития отрасли. Однако, несмотря на значительный прогресс, распространение заболеваний остаётся серьёзной проблемой: до 6–8 % личинок погибает до стадии окукливания [3]. Возникающие экономические потери значительны, что делает разработку и внедрение современных мер профилактики и контроля одной из главных задач отрасли.

В последние годы в шелководстве активно внедряются экологически чистые и ресурсосберегающие технологии, направленные на снижение потерь и повышение качества коконов [4,5]. Среди них особое внимание привлекает ультрафиолетовое (УФ) излучение благодаря его выраженным бактерицидным и иммуномодулирующим свойствам. Известно, что УФ-лучи поглощаются всеми биологически важными структурами клеток, поскольку их энергия достаточна для ионизации атомов [6]. Даже при малых дозах УФ-излучение оказывает стимулирующее воздействие, усиливая обмен веществ, активируя биосинтез витамина D и повышая неспецифическую резистентность организма [7,8].

Воздействие УФ-излучения на живые организмы зависит от дозы, длины волны и условий экспозиции. Наиболее эффективным бактерицидным диапазоном является длина волны около 253,7 нм, обеспечивающая инактивацию бактерий, вирусов, грибов, а также разрушение бактериальных токсинов [9,10]. В сельском хозяйстве оптимальные дозы УФ-излучения способствуют стимуляции роста растений, повышению их иммунитета и ускорению физиологических процессов [11,12]. По аналогии, в шелководстве УФ-излучение может применяться для:

- обеззараживания воздуха в инкубаториях и помещениях для выкормки;
- стерилизации поверхности яиц шелкопряда;
- подавления патогенной микрофлоры в среде содержания;
- стимуляции метаболических процессов у личинок, что способствует повышению их выживаемости [13].

Ряд исследователей [14] отмечали, что световое и УФ-облучение способны изменять параметры роста шелкопряда: личинки активнее развиваются

под фиолетовым светом; дополнительное освещение на ранних стадиях увеличивает урожай коконов и шелка до 6 %; чрезмерное облучение кварцевыми лампами замедляет рост личинок; в то время как УФ-обработка яиц повышает оживляемость и жизнеспособность личинок [15]. Таким образом, при умеренных дозах УФ-излучение выполняет двойную функцию — подавляет патогенную микрофлору и одновременно выступает биостимулятором развития шелкопряда.

Использование бактерицидных ламп для дезинфекции воздуха и обработки яиц является, следовательно, экологически чистым, экономичным и высокоэффективным методом [16]. В отличие от химических средств, УФ-излучение не оставляет токсичных остатков, не требует дорогостоящих реагентов и может применяться многократно. При правильном дозировании оно обеспечивает снижение заболеваемости личинок, повышение выживаемости и продуктивности, а также получение более качественных коконов. В совокупности эти факторы делают УФ-излучение перспективным биотехнологическим инструментом профилактики заболеваний в шелководстве, особенно актуальным для промышленного и круглогодичного разведения [17].

МАТЕРИАЛЫ И МЕТОДЫ

Весной 2023–2025 гг. в Научно-исследовательском институте шелководства (г. Ташкент) были проведены экспериментальные исследования по инкубации и выкормке личинок тутового шелкопряда (*Bombyx mori* L.) гибрида «Навруз 3».

В ходе экспериментов использовалось следующее оборудование:

- бактерицидные УФ-лампы ($\lambda = 254$ нм, 90 Вт);
- электромагнитная система ионизации воздуха.

Целью применения данного оборудования являлась дезинфекция воздуха и поверхностей в инкубаториях и выкормочных помещениях. Выкормка осуществлялась в соответствии со стандартными агротехническими требованиями для белококонных пород шелкопряда (Михайлов, 1983; Лобанов, 2020).

Экспериментальная площадка включала три инкубационно-выкормочных помещения объёмом по 60 м³ каждое, оснащённые бактерицидными лампами. Мощность ламп рассчитывалась по санитарной норме — 1 Вт ультрафиолетового излучения на 1 м³ воздуха [18]. Лампы располагались в противоположных направлениях для обеспечения равномерного распределения света, а интенсивность излучения контролировалась с помощью дозиметра.

Обзор научной литературы и собственные данные подтверждают, что электрофизические факторы (электрические и магнитные поля, оптическое излучение, ультразвук, искровой разряд и др.) оказывают выраженное воздействие на живые клетки [19]. Основным эффектом их действия является активация обменных процессов и стимуляция разви-

Ультрафиолетовое излучение (УФИ) представляет собой электромагнитные волны в диапазоне 100–400 нм и подразделяется на:

- УФ-А (315–400 нм);
- УФ-В (280–315 нм);
- УФ-С (200–280 нм).

Наиболее выраженное бактерицидное действие оказывает диапазон УФ-С, при максимальной эффективности на длине волны 253,7–254 нм.

Механизм действия УФ-облучения на микроорганизмы, находящиеся на поверхности яиц шелкопряда, основан на двух основных процессах:

1. Фотохимическое повреждение ДНК — поглощение фотонов вызывает образование тиминовых димеров и блокировку репликации, что приводит к гибели микробных клеток в первом или последующих поколениях.

2. Денатурация белков и ферментов — локальный нагрев и межмолекулярное трение в мембранах вызывают инактивацию ферментов и разрушение мембран.

Патогенные микроорганизмы, обладающие более высоким содержанием воды в клетках по сравнению с яйцами шелкопряда, подвергаются избирательному нагреву, что приводит к их уничтожению. При этом структура яиц остаётся неповреждённой, что делает данный метод безопасным и экологически чистым.

Дополнительно воздействие постоянного электрического поля вызывает поляризацию фосфолипидного бислоя и изменение мембранного потенциала (50–70 мВ), нарушая транспорт ионов K^+ и Na^+ ,

что приводит к блокировке метаболизма в микробных клетках.

РЕЗУЛЬТАТЫ И ОБСУЖДЕНИЕ

Анализ литературных данных по электрофизическим и электротехнологическим методам дезинфекции биологических объектов, а также собственные исследования по стимуляции шелкопряда с применением электрофизических воздействий подтверждают наличие общих закономерностей. Любое электрофизическое воздействие — будь то электрические и магнитные поля, оптическое излучение, электромагнитные волны, искровой разряд, электрический ток или ультразвук — оказывает влияние на живые клетки, вызывая активацию метаболизма, что приводит к ускорению развития и повышению жизнеспособности организмов.

В рамках экспериментов по инкубации и оживляемости яиц шелкопряда (*Bombyx mori* L.) были испытаны различные режимы воздействия бактерицидных ультрафиолетовых ламп ($\lambda = 254$ нм).

Экспериментальные варианты:

I. Облучение в течение 10 минут один раз в сутки.

II. Облучение в течение 30 минут один раз в сутки.

III. Облучение двумя лампами в течение 30 минут один раз в сутки.

IV. Контроль (без облучения).

Каждый вариант имел 5 повторов, при этом в каждом повторе размещалось по 100 яиц. В ходе эксперимента оценивалась оживляемость яиц шелкопряда, результаты которой приведены в таблице 1.

Таблица 1.

Процент оживших яиц гибрида «Навруз 3» (2023–2025 гг.)

Вариант	Количество инкубируемых яиц, шт.	Количество оживших яиц, шт. $\bar{X} \pm SD$	Количество не-оживших яиц, шт. $\bar{X} \pm SD$	Процент оживления, % $\bar{X} \pm SD$	Pd
I	100	95.0 ± 1.3	5.0 ± 0.9	95.0 ± 0.93	0.884
II	100	97.0 ± 1.0	3.0 ± 0.93	97.0 ± 0.93	0.825
III	100	99.0 ± 1.3	1.0 ± 0.9	99.0 ± 0.9	0.806
IV (контроль)	100	95.0 ± 0.9	5.0 ± 0.93	95.0 ± 0.9	—

Примечание: Данные приведены в среднем по пяти повторностям

Результаты показали, что в опытных группах процент оживления яиц был выше, чем в контрольной (95,0 %). При 10-минутном облучении уровень оживления достиг 99,0 % (+4,0%), тогда как при 30-минутном воздействии также наблюдалось улучшение показателей, хотя эффект выражен слабее. В третьем варианте эксперимента — при использовании двух ламп в течение 30 минут — процент оживления составил 95,5 %, что было сопоставимо с контролем. Аналогичные результаты были получены ранее (Роскин, 1972; Михайлов, 1983), где отмеча-

лось, что умеренные дозы УФ-излучения повышают уровень оживляемости и жизнеспособность личинок.

При выкормке личинок в помещениях, где применялось ультрафиолетовое облучение, на каждом этапе линьки проводился строгий контроль за отсутствием заболеваний. Кроме того, начиная с третьего возраста и до начала образования коконов на пятом, проводилось взвешивание личинок — случайно отбирали по 50 экземпляров для определения их общей массы (см. таблицу 2).

Таблица 2.

Средняя масса личинок гибрида «Навруз 3» на III–V возрастах (2023–2025 гг.)

Вариант	Год	Масса 50 личинок III возраста, г	Масса 1 личинки, г	Масса 50 личинок IV возраста, г	Масса 1 личинки, г	Масса 50 личинок V возраста, г	Масса 1 личинки, г
I	2023	4.20	0.084	16.94	0.339	80.02	1.60
	2024	3.92	0.078	16.62	0.332	78.30	1.57
	2025	4.10	0.082	16.80	0.336	79.16	1.58
Среднее		4.07 ± 0.082	0.081 ± 0.002	16.79 ± 0.093	0.336 ± 0.002	79.16 ± 0.497	1.583 ± 0.003
Pd		0.833	—	0.106	—	0.006	—
II	2023	4.21	0.084	17.55	0.351	80.15	1.60
	2024	4.09	0.082	16.78	0.336	78.47	1.57
	2025	4.19	0.084	17.10	0.342	79.95	1.59
Среднее		4.16 ± 0.037	0.083 ± 0.001	17.14 ± 0.223	0.343 ± 0.006	79.52 ± 0.530	1.590 ± 0.009
Pd		0.196	—	0.045	—	0.005	—
III	2023	4.30	0.086	17.95	0.359	80.67	1.61
	2024	4.18	0.084	16.98	0.340	78.97	1.58
	2025	4.28	0.086	17.45	0.349	80.15	1.60
Среднее		4.25 ± 0.037	0.085 ± 0.001	17.46 ± 0.280	0.349 ± 0.006	79.93 ± 0.503	1.600 ± 0.009
Pd		0.030	—	0.025	—	0.004	—
IV (контроль)	2023	4.11	0.082	16.23	0.325	72.30	1.45
	2024	4.05	0.080	15.10	0.302	68.70	1.37
	2025	4.12	0.082	16.12	0.322	70.20	1.40
Среднее		4.09 ± 0.022	0.082 ± 0.001	15.82 ± 0.360	0.316 ± 0.007	70.40 ± 1.044	1.408 ± 0.008

Примечание: Данные приведены как среднее значение ± стандартное отклонение (n = 3 года).

Значительные различия были выявлены на стадии пятого возраста: общая масса 50 личинок в опытных вариантах (I–III) составляла от 79,87 до 79,92 г, тогда как в контроле (вариант IV) — 70,40 г. Это соответствует увеличению примерно на 13,5 %, что является существенным показателем для продуктивности шелководства. Средняя масса одной личинки возросла с 1,42 г в контроле до 1,59–1,60 г в опытных вариантах, то есть прирост составил 0,17–0,18 г на особь. Хотя эти различия могут показаться незначительными, при пересчёте на популяционный уровень они приводят к заметному

увеличению выхода коконов и производства шелка-сырца.

На основе данных таблицы была составлена гистограмма, отражающая среднюю массу гусениц шелкопряда III–V возраста с наилучшими показателями. На рисунке 1 чётко видно различие между опытными и контрольным вариантами. Согласно литературным данным, масса личинок тесно коррелирует с массой кокона и выходом шелковой оболочки [3,7].

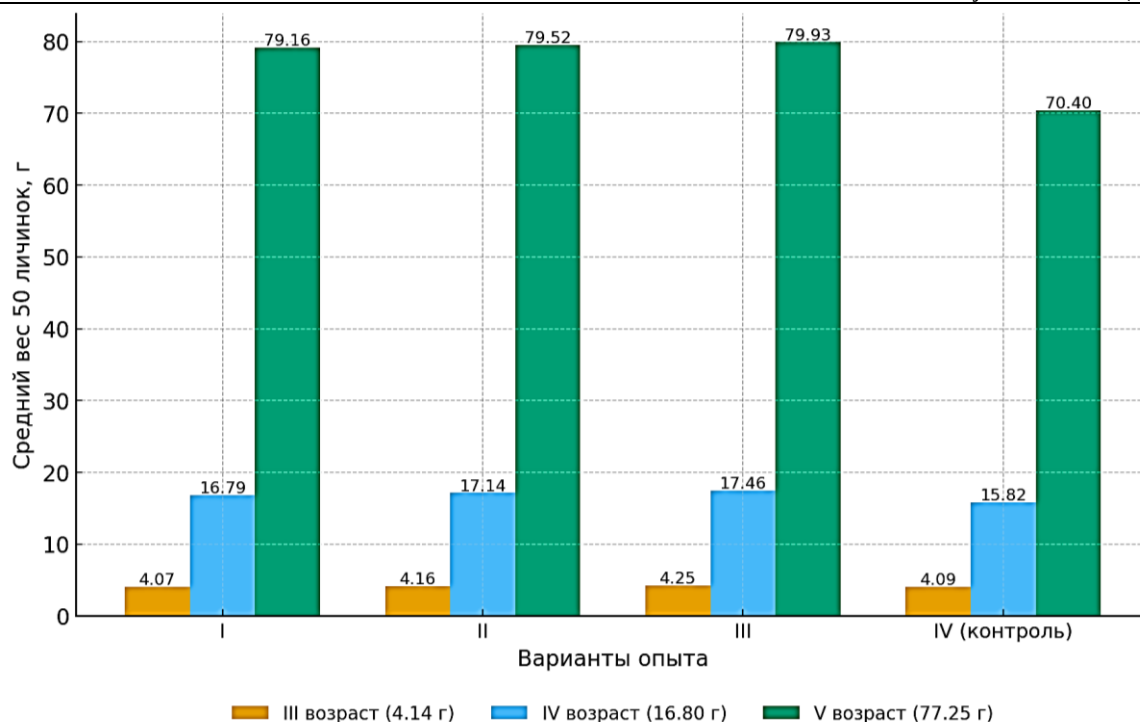


Рисунок 1. Средний вес 50 личинок тутового шелкопряда (III–V возрасты) по вариантам.

Наши результаты подтвердили данную взаимосвязь: ультрафиолетовое облучение не только обеспечивало дезинфекцию помещений, снижая микробную нагрузку, но и повышало продуктивность личинок. Отмеченное увеличение биомассы на поздних возрастах указывает на то, что УФ-обработка, вероятно, оказывает положительное влияние на эффективность метаболизма и усвоение корма, что, в свою очередь, способствует формированию более тяжёлых и качественных коконов.

Полученные результаты подчёркивают двойную роль ультрафиолетового облучения: с одной

стороны, оно выступает как профилактическая мера, снижающая уровень заболеваемости, а с другой — как стимулятор роста, способствующий повышению продуктивности. Такое сочетание эффектов делает УФ-технологии ценным и экологически безопасным элементом современной системы шелководства.

В ходе экспериментов определялись биологические показатели, включая выживаемость шелкопряда, уровень заболеваемости и продолжительность личиночной стадии. Эти данные приведены в таблице 3.

Таблица 3.

Биологические показатели личинок гибрида «Навруз 3» (2023–2025 гг.)

Вариант	Продолжительность личиночной стадии, сут.	Заболеваемость, % $\bar{X} \pm SD$	Pd	Жизнеспособность, % $\bar{X} \pm SD$	Pd
I	27	2.10 ± 1.30	0.294	86.5 ± 5.78	0.151
II	27	1.10 ± 0.67	0.679	89.6 ± 1.23	0.591
III	26	1.06 ± 0.69	0.679	90.1 ± 1.36	0.673
IV (контроль)	27	3.10 ± 0.97	—	84.3 ± 3.53	—

Примечание: Данные представлены как средние значения $\pm$ стандартное отклонение ($n = 5$).

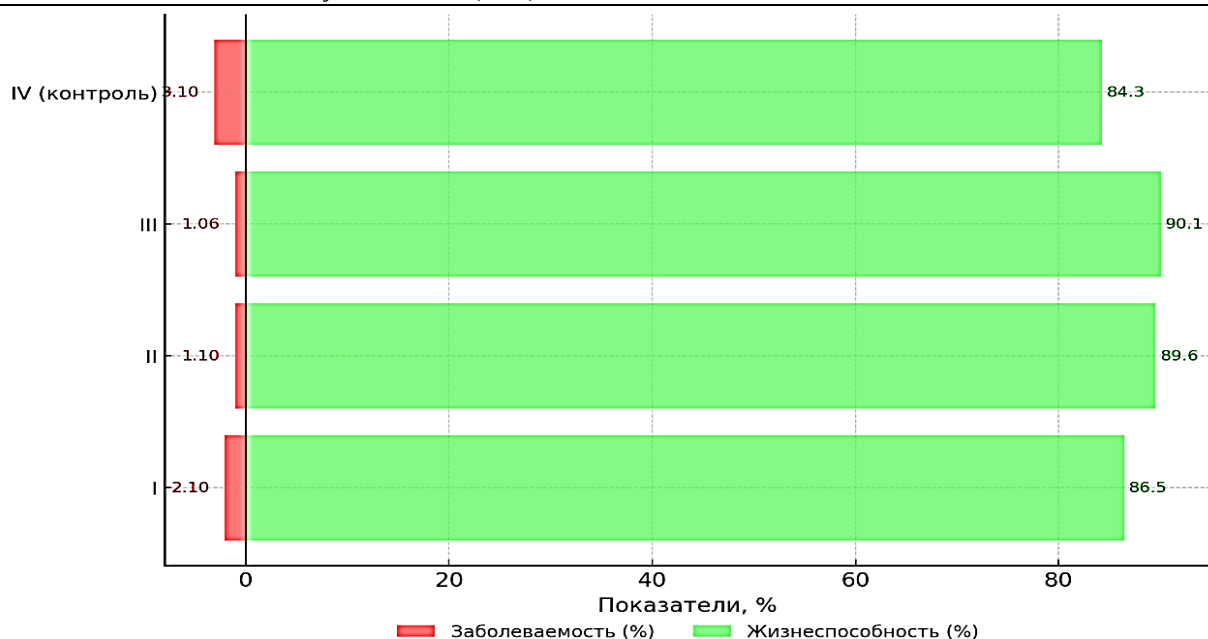


Рисунок 2. Биологические показатели личинок шелкопряда.

После УФ-облучения выживаемость личинок повысилась до 86,5–90,1 % по сравнению с 84,3 % в контроле, что соответствует приросту на 2,2–5,8 %. Среди всех вариантов наилучшие результаты показал третий вариант (облучение двумя УФ-лампами в течение 30 минут), где уровень выживаемости достиг 90,1 %.

Аналогичная тенденция наблюдалась и по показателю заболеваемости: в контрольной группе он составлял 3,1 %, тогда как в опытных вариантах снизился до 1,06–2,1 %. Минимальное значение (1,06 %) вновь зафиксировано в третьем варианте, что подтверждает высокую эффективность двойного облучения. Это указывает на то, что более интенсивное воздействие УФ-излучения, при условии

строгого контроля дозы, обеспечивает более выраженный бактерицидный эффект без отрицательного влияния на здоровье личинок.

Важно отметить, что продолжительность личиночной стадии оставалась стабильной — 26–27 суток во всех вариантах, включая двойное облучение. Это означает, что несмотря на улучшение выживаемости и физиологического состояния, темпы развития не изменились, что крайне важно: любое удлинение цикла увеличивает затраты на корм и риски при содержании.

Показатели продуктивности коконов (в среднем по 5 повторностям) приведены в таблице 4 и на рисунке 3.

Таблица 4.

Технологические показатели коконов									
Вариант	Масса 1 кокона, г		Средняя масса, г $\bar{X} \pm SD$	Масса шелковой оболочки, г		Средняя масса, г $\bar{X} \pm SD$	Шелконосность коконов, %		Средняя, % $\bar{X} \pm SD$
	♀	♂		♀	♂		♀	♂	
I	1.6	1.5	1.54 ± 0.03	0.350	0.353	0.352 ± 0.007	21.8	22.9	22.9 ± 0.2
II	1.6	1.5	1.55 ± 0.04	0.349	0.344	0.346 ± 0.010	21.9	23.1	22.3 ± 0.1
III	1.7	1.5	1.60 ± 0.01	0.379	0.352	0.365 ± 0.005	22.3	23.3	22.8 ± 0.2
IV (контроль)	1.5	1.4	1.50 ± 0.05	0.307	0.301	0.304 ± 0.006	20.7	21.1	20.3 ± 0.1

Примечание: Данные представлены как средние значения $\pm$ стандартное отклонение ($n = 5$).

Данные по продуктивности коконов (в среднем по пяти повторностям) демонстрируют устойчивое преимущество групп, подвергшихся УФ-облучению, по сравнению с контролем. Масса как кокона, так и шелковой оболочки была выше в

опытных вариантах, что указывает на улучшение усвоения питательных веществ и повышение жизненной активности личинок при содержании в обеззараженной и биостимулированной среде.

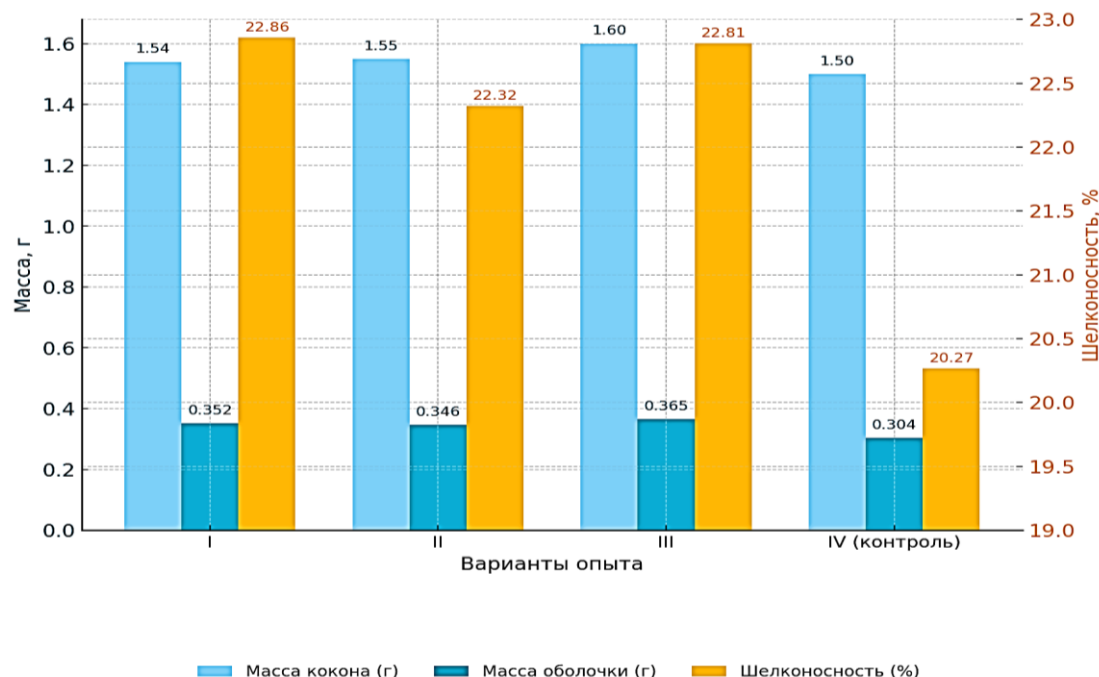


Рисунок 3. Технологические показатели коконов

Шелконосность (доля шелка в коконе) достигала 22,4–22,9% в вариантах с УФ-облучением против 20,3 % в контроле, что свидетельствует о явном повышении выхода шелка-сырца. Несмотря на то, что различия по отдельным показателям составляют всего 0,1–0,5 % относительно других УФ-групп и 1,5–2,6 % по сравнению с контролем, при переводе этих данных в промышленные масштабы они приобретают статистическую и экономическую значимость.

Особое внимание следует уделить варианту III (30-минутное облучение двумя лампами). В этом режиме были достигнуты наибольшая масса кокона (1,60 г), масса шелковой оболочки (0,365 г) и максимальный коэффициент шелконосности (22,9 %). Эти показатели превосходят как контроль, так и другие варианты, что подтверждает: продолжительное, но сбалансированное УФ-воздействие создает оптимальные санитарные и физиологические условия для развития шелкопряда.

Полученные результаты согласуются с данными как международных, так и отечественных исследований. Так, [20] показали, что УФ-облучение повышает иммунитет насекомых, а [21,22] сообщили об эффективности метода для инактивации патогенов без применения химических реагентов. Классические работы Михайлова (1983) и Роскина (1972) также подтверждают, что использование бактерицидных ламп снижает заболеваемость и повышает выживаемость личинок шелкопряда. [23] выделяют УФ-дезинфекцию как эффективное средство снижения микробной нагрузки в шелководческих помещениях.

Следует также отметить, что при УФ-облучении происходит образование озона, обладающего дополнительным дезинфицирующим эффектом [24,25]. Однако избыточное накопление озона может оказывать негативное воздействие на

личинок и обслуживающий персонал. Поэтому после сеанса облучения рекомендуется кратковременное проветривание (5–10 минут) для поддержания безопасных санитарных условий [26,27].

ВЫВОДЫ

Результаты экспериментов показали, что в помещениях для выкормки, где применялось ультрафиолетовое облучение, не наблюдалось случаев заболеваний, задержки развития или массовой гибели личинок. Риск микробного заражения из кормовой или внешней среды был значительно снижен. Кроме того, повысились жизнеспособность и масса личинок, что привело к увеличению урожая коконов и улучшению их качества.

Таким образом, проведенные исследования подтверждают, что ультрафиолетовое облучение, особенно при режиме двух ламп в течение 30 минут, является эффективным, экологически безопасным и экономически обоснованным агроэлектротехнологическим методом для профилактики заболеваний и повышения продуктивности в шелководстве.

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POLITICAL SCIENCES

ANALYSIS OF DATA ON GENDER-BASED VIOLENCE AND WOMEN'S PARTICIPATION IN ELECTED OFFICE IN TIJUANA AND MEXICALI

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Abstract

This paper analyzes data on women's participation in politics and violence against women in Tijuana and Mexicali, as well as contextual elements from Baja California. Tijuana and Mexicali are used as case studies. The paper hypothesizes that "even though women have held elected office, this has not had an impact on reducing indicators of violence against women." It also broadly reviews the institutional policies implemented to reduce the gender gap through women's participation in public decision-making. While, in political terms from a democratic perspective, we can infer that this is considered an element for the consolidation of this model, in pragmatic terms for society, it has not been reflected in facts that can be demonstrated by concrete data.

Keywords: Democracy, women's political participation, reduction of violence against women.

Introduction

The fight for gender equality has been a rocky road with great challenges, of which it can be said that from the emergence of peaceful and non-peaceful demonstrations by women to make their voices heard, in the old world of the last century, they were the turning point that gave rise to a period of social recognition of women in decision-making regarding who might be suitable to govern, of which we must not forget that even in some places considered liberal democracies they did not have the right to property or employment in the last century.

The greatest leaps forward came when women gained the right to participate in elections, but only with the right to vote, not to be elected, as that prerogative was reserved solely for the male gender. Even during this period, in some countries with totalitarian tendencies, if someone was caught engaging in any practice contrary to traditional reproduction, it was considered a serious crime and consequently severely punished. Therefore, there was little chance that women would ever have the rights that are basic in many countries today, much less be considered eligible for political office, which may have seemed incongruous and absurd at the time.

The construction of the new American world, emphasized the need to consider the role of women in political processes, but before political rights were expected civil rights would be a reality where private property was the main need for the citizen and a utopia for women in the 19th century and early 20th century [given that most countries] did not have the legal right to property, even in parliamentary governments.

Currently, the scenarios for women have changed for the benefit of this gender, however, that does not mean that the ideals of equity that are sought have been achieved, but the great strides have represented great challenges in the design and implementation of policies, since parallel to these achievements, there is still an extremely important element and that is the cultural aspect, which, like the "Deep State", is so rooted in social groups that a radical change will not be possible

when dictating and implementing a social policy for gender equity, but under the incrementalist scheme, the structures will have to be changed step by step with the objective of achieving balances that allow the full development of all genders, if it is in the interest of said governments and societies.

Thus, while this paper aims to explain the 21st-century phenomenon of the impact of elected women in decision-making positions, it uses a comparative case study between the cities of Tijuana and Mexicali. Therefore, it hypothesizes that "even though women have held elected office, this has not had an impact on the reduction of indicators of violence against women." In other words, having more women in the public administration system does not imply that conditions for women are improving, and that these changes are reflected in positive changes reflected in terms of impact. While this is considered a somewhat pessimistic scenario, the truth is that, in order to give these new women a vote of confidence, we must remember that they arrived in an administrative system designed by men. On the other hand, it is recognized that there is pressure from the international context to position women in elected office, a phenomenon that responds to the United Nations resolution of 2011, which specifically states the following: "Women continue to be largely marginalized from the political sphere throughout the world, often as a result of discriminatory laws, practices, attitudes and gender stereotypes, low levels of education, lack of access to health care services, and because poverty affects them disproportionately."

While some United Nations member countries have decades of experience with women in politics, for the vast majority, it is still part of the pending agenda. For Mexico, it has also been a complicated task; however, it is now evident that the role of women in politics is increasingly active and they are increasingly present in impactful decision-making.

Basic Ideas about Democracy

The concept of democracy has been considered one of the most important for the construction of the

Liberal State; however, this has not meant that democracy is the same for all nation-states in the world, especially for those that have not adopted any type of democratic trait. However, in the strictest sense, a democracy is a regime where structures have been designed so that all those who wish to participate within the system can participate, giving the opportunity for this participation to be a choice and not an imposition (Morlino, 1995).

It is for this reason that the quality of democracy is currently being debated, which has been measured solely through quantitative electoral aspects, that is, a democratic system is of quality if the greatest possible number of voters participated in an electoral process x (Morlino, 2005). However, our opinion differs with regard to the idea of quality, since if an element of quality is going to be attributed to something like "democracy", this analysis should be accompanied by other elements that have no relation to the size of the electorate and its participation in the elections, but rather with deontological reasons, about the expectations that a democratic model must meet. Therefore we suggest thinking that to decide if a regime is democratic with quality it should be covered by good results in the quality of life indicators and not be distracted by merely political issues, it is not denied that it may be a reason for a political issue to potentiate a scenario at a certain given time, but why deceive ourselves intellectually if we know that democracy is not good for eating, that is, Why should we give our trust to a person who does not know us to make decisions about our lives and define rules for our lives as citizens and non-citizens? Another necessary question is if this person is not looking for our good in community why should we trust them? These are the questions that should be asked when questioning about the quality of democracy, For what reason? Although the individual of the twentieth and twenty-first centuries has not had much opportunity to generate great changes in the systems, they have been born, grown and have adapted to the different systems previously established and designed by past generations, however the approach is that democracy remains the same, but we must advance in expectations For democracy, knowing how many people voted in an election won't help us feed our families. What will be useful is for those who are elected to govern who meet expectations by creating the socioeconomic conditions for a

better life. One of the best arguments for not transitioning to authoritarian regimes is that democracy would lead a better life. In this sense, we mean that individuals must have the opportunity to develop under equal conditions, and that these conditions cannot be temporary for political reasons, but must be part of the institutional model, which includes a gender perspective.

Therefore, our methodology considers security as one of the indicators of quality of life. This study specifically analyzes the gender-based violence index. It is hypothesized that increased female participation in elected office is not necessarily reflected in a decrease in indicators of violence against women. Data from Tijuana and Mexicali are used as case studies: the former because it is a secondary city in the state of Baja California, with the geographic implications of this status, and the latter because it is the state's capital. Another common characteristic is that both cities are border cities. Finally, inferences are drawn about their relationship with the violence indicators.

The first step is to understand the contextual aspects for Baja California, which is why the main data for the state and for each of the two cities, Tijuana and Mexicali, are presented below.

Socioeconomic contextual aspects in Baja California: Emphasis on Tijuana and Mexicali

One of the widespread beliefs in Mexico is that the northern region is believed to have better conditions in all aspects of the population's socioeconomic life. Although, in terms of job opportunities along the Baja California border, there are many employment opportunities in the maquila and service industries, there are still gaps in the supply of good opportunities and also inequality of opportunity for men and women. According to data obtained by the National Institute of Statistics, Geography, and Information in 2020, there were 3,769,020 people residing in Baja California, 49.6% women and 50.4% men. The median age in the state is 30 years. Of every 100 pesos contributed to the Baja California economy, 60.92 are from tertiary activities, 36.02 from secondary activities, and 3.06 from primary activities. Although the percentage of men in Baja California is higher than the total population, this section will examine the extent to which women have participated in activities related to the community's economic, political, and social development.

Table 1

Comparison by gender of five-year labor contribution.

En- tity fed- eral	Five- year age group	2005			2010			2020		
		Total	Men	Women	Total	Men	Women	Total	Men	Women
Baja Cali- for- nia	Total	2,844,469	1,431,789	1,412,680	3,155,070	1,591,610	1,563,460	3,769,020	1,900,589	1,868,431

Prepared by the authors using data from INEGI.

In Tijuana, the population according to INEGI data in 2020 was 1,922,523 inhabitants, while in Mexicali it was 1,049,792 inhabitants in the same year. Of

these, the population is distributed as follows: 953,783 females and 968,740 males in Tijuana, while in Mexicali the population is 520,544 females and 529,248

males. To date, current President Sheinbaum is considering conducting a new population census, so the results are expected in the following months or by 2026.

Regarding economic activity, Tijuana, being one of the most important border cities in the world, and especially in Baja California, is characterized by a unique dynamism and a high-impact development capacity. By 2024, it registered exports of \$39.952 billion USD, with a presence in the medical, automotive, and transportation sectors, in general across a wide range of the manufacturing sector. Regarding international trade, in May of this year 2025, it registered international purchases of US\$2.944 billion, and international sales of US\$3.246 billion, according to data from the Mexican Ministry of Economy. Regarding its exports, the United States was its main destination, registering US\$32.882 billion in 2024, where monitors and projectors that do not incorporate television reception devices were the main exported product (Ibid.).

Meanwhile, in the city of Mexicali, despite being the capital, its economic activity is not as agile and dynamic as its sister city across the border, Tijuana. Official data from the Ministry of Economy of the Mexican federal government show that for 2024, it registered a total of US\$11.653 billion in exports, with the United

States as the main destination and integrated electronic circuits as the main product. Meanwhile, imports for 2024 amounted to US\$7.579 billion, again with the United States as the main origin and integrated electronic circuits as the main product. However, other products are imported, such as valves, air pumps, electrical wires and cables, plastic items, among others.

One of the advantages of geographic location is precisely the ability to share products, which allows for the creation of other types of links such as cultural and social ones. This has been demonstrated in different border areas as well as in northern Mexico with the United States, sharing culture which includes problems of crime incidence, although this work only addresses the issue for Tijuana and Mexicali, cities in the federal entity of Baja California, Mexico.

Some political background in Mexico

In Mexico, the history of women's political participation has been documented since Carmen Serdán's 1910 participation during Francisco I. Madero's anti-re-election campaign. Hermila Galindo was later singled out in 1918 as one of the key figures who promoted women's political rights. The following table shows some of the most relevant data regarding women's political participation in this country.

Table 2

Background of women's political participation in Mexico.

Year	Event
1918	Hermilia Galindo petitioned the 1916-1917 Constituent Congress to recognize women's political rights (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1922-1924	Elvia Carrillo, the first candidate elected to the Yucatán Congress, served only two years in office (Alejandre Ramírez and Torres Alonso, 2016).
1922-1924	In Yucatán, women were allowed to vote in local and state elections (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1924-25	In San Luis Potosí, a law was passed allowing literate women to participate in the municipal elections of 1824 and the state elections of 1824 (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1934	The Mexican Women's Front was formed, and the leader of the National Revolutionary Party called for the formation of the party's Women's Sector. Its first leader was Edelmira Rojas, widow of Escudero (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1935	Lázaro Cárdenas transformed the Women's Sector into a Women's Action Office, dependent on the National Executive Committee. Its first director was Margarita Robles, with whom she founded the United Front for Women's Rights, which fought for the right to vote, the expansion of literacy programs, daycare centers, maternity wards, and hospitals, and brought women into the political struggle. Its leaders included Consuelo Uranga, Frida Kahlo, Adelina Zendejas, and María del Refugio García (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1936	In Puebla, Article 33 of the local Electoral Law was amended, recognizing that "men and women of Puebla are voters and therefore have the right to be registered on the electoral roll" (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1936	The Inter-American Women's Committee for Democracy is consolidated (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1937	Lázaro Cárdenas sends the initiative to reform Article 34 of the Constitution to the Senate as a first step toward women obtaining citizenship. The initiative failed (Law on

	Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1938	The United Front, founded in 1935, launches an intense campaign to reform Article 4 of the Constitution to recognize women's political rights. The movement finds support in 21 states, but not in the Congress of the Union (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010)
1941	The national women's alliance, which called for women's access to public office, was highlighted. As a result of this movement, Matilde Rodríguez was appointed head of department and Palma Guillen was appointed Mexican ambassador to Colombia (Ramos Escandón, 1994).
1946	The Congress of the Union approved the initiative submitted by President Miguel Alemán, adding Article 115 to the Constitution to establish that women would participate in municipal elections on equal terms with men, with the right to vote and be elected. The reform went into effect on February 12 of the following year (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1947	María del Carmen Marín del Campo became the first female mayor of Aguascalientes (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1953	In an ordinary session of the Chamber of Deputies, Articles 34 and 115, Section I, of the Political Constitution of the United Mexican States were declared amended to establish that: "Citizens of the Republic are men and women who, being Mexican, also meet the following requirements: be at least 18 years of age if married, or 21 if unmarried, and have an honest livelihood" (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1953	The right of women to vote and to be voted for is recognized. (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1954	Aurora Jiménez de Palacios, First Federal Deputy for District I of the State of Baja California. (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1955	Women go to the polls, for the first time nationwide, to elect federal deputies to the 43rd Legislature (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1958	Macrina Rabadán becomes the first federal deputy from an opposition party—the Popular Socialist Party—to represent the State of Guerrero in the 44th Legislature (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1967	Alicia Arellano Tapia and María Lavallo Urbina became the first two female senators of the Republic, representing Sonora and Campeche, respectively, in the 46th and 47th Legislatures. Lavallo Urbina later became President of the Senate (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1971	The feminist organization Women in Solidarity Action (MAS) is born. This is the first in a series of feminist groups influenced by American and European feminism after 1966. Since then, feminism has championed the phrase "the personal is political" (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1975	International Women's Day is established by the UN and is celebrated every March 8 (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1979	Griselda Álvarez Ponce de León becomes the first female Governor of Mexico for the State of Colima. (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1980	The National Program for the Integration of Women into Development is created, dependent on CONAPO (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1985	The National Women's Commission is created, attached to the Ministry of the Interior (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1993,	Approval of the gender quota (Article 115 of the Federal Code of Electoral Institutions and Procedures). (Electoral Institute of the State of Sinaloa, 2007).

1997	Candidacies for deputies or senators must not exceed 70% for the same gender (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1988	Ifigenia Martínez Hernández becomes the first senator from an opposition party, as part of the 54th Legislature (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1993	Reform to COFIPE requires parties to nominate more women for elected office (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1993	Approval of the gender quota (art. 115 of the Federal Code of Electoral Institutions and Procedures).
1996	The Government of Mexico creates the National Women's Program (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
1997	Candidacies for deputies or senators should not exceed 70% for the same gender (Reynoso, D., & D'Angelo, N, 2006).
2000	The Mexiquense Women's Institute is created (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
En 2002	Political parties must register at least 30% of their candidates for elected office as women; additionally, on multi-member lists, one woman for every three men (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
El 2 de agosto de 2006	The General Law on Equality between Men and Women was published, which aims to guarantee equal opportunities and treatment between men and women (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
2007	The General Law on Women's Access to a Life Free from Violence (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010) was enacted.
2019	A series of constitutional reforms were approved to achieve parity in all three branches and levels of government, as well as autonomous bodies (Law on Equal Treatment and Opportunities between Women and Men of the State of Mexico, Decree No. 145, 2010).
2020-2021	In the largest electoral process by number of elected positions, women won more than six governorships, and parity was achieved in the Chamber of Deputies (50/50) and in almost all local governments (National Electoral Institute, 2022).

Source: Prepared by the authors using third-party information.

Women's participation in Baja California politics: electoral processes

In Baja California, the State Electoral Institute (IFE) has existed since 1994, serving as the autonomous state body for organizing local elections. The following tables show historical information from the 1995-1998 municipal elections in Tijuana and Mexicali. For the Tijuana data, it is noteworthy that during the first terms of government, women's participation in elected office was 30.76%, the same as in Mexicali. During the 1998-2001 period, women represented 13.33% in Tijuana, while in Mexicali it remained at 30.76%. In the 2001-2004 period, women represented

14.28% and 30.76% in Mexicali. In the following period, from 2004-2007, women represented 21.42% in Tijuana and 23.07% in Mexicali. In the 2007-2010 period for both cities it was 30.76%; in the 2010-2013 period it was 54.54% for Tijuana and 88.88% for Mexicali; in the 2013-2016 period for Tijuana and Mexicali it was 41.66%; in the following period from 2016-2019 it was 70% for Tijuana and 88.88% for Mexicali; in the 2019-2021 period it was 88.88% for Tijuana and Mexicali, and the same will be true for the 2021-2024 period.

Below is a list of women in current public administrations by municipality of Tijuana and Mexicali.

Table 3.

Historical distribution of positions by gender in Tijuana

Tijuana	Relative majority									Representation Proportional			Total	
	P	S	R1	R2	R3	R4	R5	R6	R7	R8	M	H	M	H
1995-1998	H	H	H	H	H	M	H	H	H	H	3	4	4	13
1998-2001	H	H	H	H	H	H	H	H	H	H	2	5	2	15
2001-2004	H	H	H	H	M	M	H	H	H	H	0	6	2	14
2004-2007	H	H	H	H	H	M	H	H	H	H	2	5	3	14
2007-2010	H	H	H	H	H	M	H	M	H	H	2	5	4	13
2010-2013	H	M	H	H	H	H	H	M	H	M	3	4	6	11
2013-2016	H	H	H	H	H	M	H	H	M	M	2	5	5	12
2016-2019	H	M	H	M	H	M	H	M	H	M	2	5	7	10
2019-2021	H	M	H	M	H	M	H	M	H	M	3	4	8	9
2021-2024	M	H	M	H	M	H	M	H	M	H	3	4	8	9
	1	3	1	2	2	7	1	4	2	4				
Totales										27	22	47	49	120

Source: Baja California State Electoral Institute (2021). Where R1, R2, ... R8, mean councilor number one and so on.

Table 4

History of the distribution of positions by gender in Mexicali

Mexicali	Relative majority									Representation Proportional			Total	
	P	S	R1	R2	R3	R4	R5	R6	R7	R8	M	H	M	H
1995-1998	H	H	M	H	M	H	H	H	M	H	1	6	4	13
1998-2001	H	H	H	M	H	H	H	H	H	H	3	4	4	13
2001-2004	H	H	H	M	H	H	H	H	M	H	2	5	4	13
2004-2007	H	H	H	H	H	H	H	M	H	H	3	4	4	13
2007-2010	H	H	M	H	M	H	H	H	H	M	1	6	4	13
2010-2013	H	H	M	M	H	M	H	H	H	H	5	2	8	9
2013-2016	H	H	M	H	H	H	M	H	M	H	2	5	5	12
2016-2019	H	M	H	M	H	M	H	M	H	M	3	4	8	9
2019-2021	M	H	M	H	M	H	M	H	M	H	3	4	8	9
2021-2024	M	H	M	H	M	H	M	H	M	H	3	4	8	9
	2	1	6	4	4	2	3	2	5	2				
Totales											31	26	44	57

Source: Baja California State Electoral Institute (2021). Where R1, R2, ... R8, mean councilor number one and so on.

As can be seen, in these municipalities there has been a clear increase in women's participation in elected office, which speaks to the importance and relevance attributed to the national policy of gender equality and political participation. However, it is notable that, in the initial periods in the city of Mexicali, the participation rate remained at four women compared to 13 men. Subsequently, with structural changes in Mexico's electoral legislation, the number of representatives per city council decreased. Although a mandatory quota for women's participation was increased, gender inequality persisted. A similar situation occurred in Tijuana, but they did not achieve the same level of equality in participation as in the city of Mexicali. In this sense, it is important to recognize that women's participation in elected office has been increasing in both cities. What we need to know is whether this has had a positive impact on the reduction of rates of violence against women in these cities, which is reviewed in the following sections.

Institutional policies implemented to reduce the gender gap

The gender issue continues to be one of the issues within government agendas, so we can find programs that have been designed and implemented at the national level with local impact to seek to reduce the gap between women and men, in such a way that the United Nations has developed a program to train public policy makers in gender matters, said program is an international cohort and is called "Programs with a gender perspective. Training for their development and implementation", and is focused on institutions developing skills that allow the design and implementation of plans, programs and initiatives to address violence against women and girls (Spotlight Initiative, 2021), which has been adopted by different organizations.

Another element to consider is the implementation of policies aimed at designing public budgets in Mexico, which should be prepared with a gender perspective. This is intended to ensure that expenditures across the entire federal public administration achieve equality between men and women in public spending (UN Women, 2018).

During the administration of the federal government in Mexico under the current President Sheinbaum, the "Comprehensive Program to Prevent, Address, Punish, and Eradicate Violence against Women" (PIPASEVM 2021-2024) was launched. This program responds to one of the objectives of the National Development Plan (PND 2019-2024) of the previous term. It is coordinated through the Ministry of the Interior, the Undersecretary of Human Rights, Population, and Migration, and the National Commission for the Prevention and Eradication of Violence against Women (CONAVIM), with the goal of eradicating violence against women.

Another program designed for the same purpose is the "Support for Women's Institutions in the Federal Entities" (PAIMEF) and the Support Program for Specialized Shelters for Women Victims of Gender Violence, their Daughters and Sons (Milenio, 2025). It is also worth remembering that the current administration eliminated women's institutions to create the Secretariat of Women. However, the background on this issue is the General Law on Women's Access to a Life Free of Violence, which was approved in 2007 (Ramírez, 2021). In this sense, for more than 10 years, the issue of eradicating gender violence has been operating with a different structure and approach. The following section analyzes data for Tijuana and Mexicali in relation to the different types of gender violence experienced in both border cities.

Indicators of violence against women: Analysis of Tijuana and Mexicali

Mexicali and Tijuana are cities that belong to the State of Baja California, one of the 32 entities of the Mexican Federation. As mentioned in previous paragraphs, these cities share the northern border with the United States; however, they have significant differences in terms of size and level of socioeconomic development. However, regarding the issue of violence, there are similarities due to the increase and decrease in both cities. The following tables, presented with official data from the Secretariat of Citizen Security of the State of Baja California, compare Tijuana and Mexicali.

Table 5.

Comparison between Mexicali and Tijuana in data on the incidence of domestic violence.

	Mexicali	Tijuana	Percentage difference
Year	Domestic violence	Domestic violence	
2015	2695	5076	88.34%
2016	2322	4540	95.52%
2017	2452	4567	86.25%
2018	3121	4823	54.53%
2019	3443	4910	42.6%

Prepared by the authors using data from INEGI (2021).

Table four shows data on domestic violence cases handled. Proportionally, there is a difference of more than 80% between Tijuana and Mexicali. However, as of September 30, 2025, according to data from the Baja California State Attorney General's Office, 10,488 cases of domestic violence were reported throughout

the state, of which 3,121 were in Tijuana and 4,185 in the city of Mexicali. Proportionally, this means that there is more domestic violence in the city of Mexicali, representing 0.40% of the total, while in Tijuana it is 0.17%.

Table 6.

Comparison of Mexicali and Tijuana in data on the incidence of Sexual Abuse.

	Mexicali	Tijuana	Percentage difference
Year	Sexual abuse	Sexual abuse	
2015	278	609	119.06
2016	289	586	102.76
2017	263	556	111.4
2018	344	607	76.45
2019	385	630	63.63

Prepared by the authors using data from INEGI (2021).

Regarding the crime of sexual abuse, as can be seen, there is a significant difference between the two cities, and contrary to expectations, the rate has not de-

creased but has remained slightly on the rise. As of September 30, 2025, 1,169 cases were recorded throughout the state of Baja California.

Table 7.

Comparison of Mexicali and Tijuana in data on the incidence of Femicide.

	Mexicali	Tijuana	Percentage difference
Year	Femicide	Femicide	
2015	3	4	33.33%
2016	2	6	200%
2017	2	5	150%
2018	6	11	83.33%
2019	5	13	160%

Prepared by the authors using data from INEGI (2021).

Regarding the crime of femicide, as can be seen, the data more than doubled in the city of Tijuana between 2015 and 2019, and the same occurred in Mexicali between 2015 and 2018. According to the latest re-

port from the Attorney General's Office as of September 30, 2025, 33 cases of femicide were recorded across the state, which proportionally represents 21.22 in each municipality.

Table 8.

Comparison of Mexicali and Tijuana in data on other sexual crimes.

	Mexicali	Tijuana	Percentage difference
Year	Other crimes that violate sexual freedom and security	Other crimes that violate sexual freedom and security	
2015	71	177	149.29%
2016	86	127	47.67%
2017	74	146	97.29%
2018	70	149	112.85%
2019	80	139	73.75%

Prepared by the authors using data from INEGI (2021).

Due to the diversity of the problem, classifications of other crimes that violate sexual freedom and security are used, which include various types of sexual assault not classified under the main violation, such as sexual abuse, sexual harassment, statutory rape, and corruption of minors (CPEB, 1989). From these data it can be observed that only in 2016 there was a significant decrease, while in 2015, 2017, and 2018 the data were very high and proportionally the city of Tijuana doubled the numbers. This scenario has not improved since in the last report from August 2025, 1,045 were registered in the city of Tijuana and 917 in the city of Mexicali, this means that from 2015 to 2025 there was a percentage increase for Tijuana of 490.39%, while for the city of Mexicali, 1,191.54%.

Conclusions

One of the State's main objectives is to guarantee the well-being of its population. This reasoning, in principle, must be interpreted through deontological considerations that have been cemented in the construction of the State through the social contract and primarily during the implementation of government models based on liberal principles. In this sense, the State generally acquired more regulatory obligations, which means that, although it yielded to private participation in the economy, this had a domino effect that impacted the regulation of social life and the government's administrative apparatus. Thus, in democratic governments, de facto powers have played a fundamental role in seeking balances in relation to the capacity to provide

services and care for their population. In this work, the gender issue was explored, with the hypothesis that even though women have held elected office, this has not had an impact on the reduction of indicators of violence against women, taking Tijuana and Mexicali in Baja California, Mexico, as a case study. Therefore, according to official data, it is verified, since two things could be inferred, first, in the city of Mexicali, there are more cases of violence against women and also greater participation of women in elected office, therefore, the fact that there are women in power does not mean a positive impact through the reduction of cases of violence. On the other hand, in the municipality of Tijuana, fewer cases of women's participation in politics were recorded, as well as fewer cases of violence against women. Another fact worth highlighting is that violence against women is proportionally more prevalent in the municipality of Mexicali than in Tijuana, even though Tijuana has almost twice the population of Mexicali. On the other hand, good practices in social support programs seeking to mitigate this problem have been observed; however, the results have been insufficient, given that both cities have shown a significant increase in violence against women. Therefore, questions remain about what measures should be implemented to combat this problem and other cultural and social actions should be considered.

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