ISSN 2695-0243
DOI 10.47451/col-038-2025

EUROPEAN SCIENTIFIC e-JOURNAL

ISSUE 38 September 30, 2025

ACTUAL ISSUES OF MODERN SCIENCE

EUROPEAN SCIENTIFIC E-JOURNAL

ISSN 2695-0243

ISSUE 38

ACTUAL ISSUES OF MODERN SCIENCE

DOI 10.47451/col-038-2025

Tuculart Edition & European Institute for Innovation Development
EU, Czech Republic
2025

Actual Issues of Modern Science. European Scientific e-Journal, 38.
Ostrava: Tuculart Edition & European Institute for Innovation Development, 2025. – 181 p.

DOI 10.47451/col-038-2025

Designed by Ekaterina Rusakova

Design Partner: International Design

Table of Contents

Technologies & Innovations

Vitaliia S. Harkusha [a][1], *Serhii Simonov* [b][2]

Determining the Impact of Street Art on the Urban Environment [1]

Abstract: This study examines the role of modern urban murals in shaping urban space and their impact on the social, cultural, and aesthetic aspects of the urban environment. It is noted that the beginning of the 20th century was marked by the birth of avant-garde ideas, which were also reflected in visual art. The article presents an analysis of some modern murals as an element of the urban environment. The main functions of murals as an element of urban development are determined. Locations where the placement of modern murals is appropriate are considered. Images of the most famous modern murals are presented, serving both aesthetic and motivational purposes. The primary types of influence of modern murals on the psychological and mental state of people have been identified. Modern urban murals serve not only a decorative function but also contribute to the spiritual enrichment of society, creating meaning and shaping the unique emotional atmosphere of the city. The main trends in the development of murals are considered. It is demonstrated that murals can convey national, social, or psychological significance, stimulating reflection and engagement with citizens. Examples of iconic urban murals are given, such as the patriotic murals "Ukraine Will Win!", Khmelnytskyi; mural "Ukrainian Soldier Sewing the Flag", Kyiv; "Beauty Will Not Tolerate", Rivne; "Russia Is NEVER Here", Kherson; "Defenders of Light", Kyiv; "Hutsulka with a Laptop – Past and Present", Ivano-Frankivsk, Ukraine. The importance of integrating murals into the urban environment, considering aesthetic norms and modern urban design strategies, is emphasised. Key locations have been identified for placing murals that harmoniously blend with the architecture and provide emotional interaction with the space. It is concluded that urban murals are not only an essential element of art but also a tool of social communication, which contributes to the harmonisation of urban space and the creation of a unique city identity.

Keywords: mural, public art, street art, urban environment.

Introduction

The late 19th and early 20th centuries marked the beginning of the emergence of avant-garde ideas, both in art and in culture as a whole. This period is also characterised by urban trends, which in turn led to the mass construction of the same type of multi-storey buildings. Street art is an integral part of big cities. Art has a significant role in the spiritual and aesthetic enrichment of the urban environment. Nowadays, the creation of the urban landscape occurs in an environment of freedom of expression and is centred on exploration and innovation.

The typical development of residential areas characterises Ukraine; most of the architecture of cities is made up of the so-called "Khrushchevkas". Most industrial cities in Ukraine are characterised by monochrome architecture created through industrial methods, which contributes to the greyness of the facades of residential buildings, which deteriorate over time. As a result of hostilities, the vast majority of them have now been destroyed. Most industrial cities in Ukraine are characterised by monotonous and faceless buildings with technically obsolete structures, poorly planned and structured territories, and growing social problems among residents. Street art is one way to make these cities vibrant and alive. For residents of

[a] Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Architecture, Pryazovskyi State Technical University. Mariupol (Dnipro), Ukraine.
[b] Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Architecture, Pryazovskyi State Technical University. Mariupol (Dnipro), Ukraine.

territories where hostilities have occurred, it can serve as a psychological release and attract creative young people to these cities (*Tyurikova & Pogorelov, 2016*).

The post-war task of urban planners and architects is to create comfortable living conditions for residents of residential areas, turning these abandoned areas into an attractive part of the city. Street art will make the restored cities even better than they were before the war and become an integral part of them.

The review of the latest sources of research and publications. The most visible and discussed form of street art is murals. The first murals were founded in Mexico in the 1920s, following the Mexican Revolution (1910–1920), when artists Diego Rivera, David Alfaro Siqueiros, and José Clemente Orozco began to create huge wall paintings that glorified freedom, labour, people, and historical heroes. Over time, murals have developed in the United States, Great Britain, and other regions, especially during conflicts in Northern Ireland, Palestine, Argentina, and Spain. Ukraine was no exception.

Allocation unresolved before parts of the general problem. Since Ukraine's independence, wall painting has been distributed exclusively in the form of "graffiti". The phenomenon of "graffiti" was not even distributed in the form of wall art, but more often mainly in the form of an act of vandalism. These were unprofessional drawings of very low quality, lacking any artistic value. Examples of such "painting" can still be seen in many cities of Ukraine, although not in such large numbers. Currently, the authorities are taking measures to eliminate such elements that distort the urban environment (*Chernyuk & Malinovska, 2007*; *Hrytsyuk, 2015*).

In Ukraine, wall images from the Soviet era in the form of mosaics have been preserved. The appearance of such elements has deteriorated significantly over time, and they require restoration work. Very often, such images contain elements of Soviet propaganda, which is unacceptable, given the events that are currently taking place in Ukraine. Therefore, the question also arises as to whether such elements should be eliminated or restored (*Ladan, 2008*).

Problem statement in a general view. The first objects of street art began to appear in Ukraine on the day of Independence in the form of graffiti, but art festivals gave them a real impetus. During the first art festival, "StreetArtFest" in Kharkiv, 40 street art objects were created, including six murals. The next wave of mural creation took place before EURO 2012; however, the events of 2014 became a powerful impetus, as murals began to be created in almost every city, outside of projects and festivals. The main themes of the murals were resistance to the aggression of the Russian Federation and patriotic symbols, which have become the main ones since the initially large-scale aggression on February 22, 2022.

The scientific novelty of this study lies in the comprehensive analysis of modern Ukrainian street art as a cultural and aesthetic phenomenon that contributes to the post-war reconstruction of urban space. The research for the first time systematically examines murals created during the period of martial law in Ukraine as a tool of socio-psychological recovery, collective identity formation, and revitalisation of the urban environment. The originality also consists in identifying the interrelation between street art, civic resistance, and the transformation of public space from the perspective of cultural resilience during wartime. The paper substantiates that murals are not merely artistic decoration but act as a communicative medium shaping the emotional and patriotic landscape of contemporary Ukrainian cities.

The subject of the study is the artistic, ideological, and socio-psychological features of Ukrainian street art (particularly murals) as a means of forming national identity and harmonising public space in the conditions of post-war reconstruction.

The object of the study is the cultural and aesthetic transformation of urban space in Ukraine during and after the war through the phenomenon of street art.

The study aims to research the aesthetic features of modern street art, its impact on the organisation of public and urban space, and the cultural and spiritual education of society during martial law.

According to the purpose of the study, research tasks are:

- analyse the historical background and evolution of street art and mural movements in Ukraine and worldwide;
- identify the socio-cultural functions of murals in the Ukrainian urban environment;
- examine thematic trends and symbolic content of murals created during martial law;
- assess the influence of street art on the restoration, emotional perception, and modernisation of Ukrainian cities;
- generalise the role of street art as an instrument of patriotic communication and cultural resilience.

Methods

The methodological framework of the research combines general scientific and specialised approaches that enable the comprehensive study of street art as an urban cultural phenomenon.

General scientific methods include:

- Analysis and synthesis, which allowed for the identification of structural and semantic elements of street art within the broader urban context.
- Induction and deduction, used to generalise specific observations of mural examples into theoretical conclusions about their socio-cultural role.
- Comparative and historical methods, applied to trace the evolution of street art from early muralist traditions to contemporary Ukrainian practices, situating them within the global art-historical process.
- Systemic and structural analysis, enabling the interpretation of murals as integral components of the urban ecosystem that influence both aesthetics and public consciousness.

Specific methods relate directly to the interdisciplinary nature of the study:

- Art-historical analysis was used to explore stylistic, compositional, and colouristic features of murals, revealing their continuity with global art movements.
- Sociocultural analysis examined the communicative and symbolic functions of street art as a form of collective response to social trauma and war.
- Semiotic analysis helped to decode the meanings and symbols embedded in wartime murals—patriotic emblems, mythological figures, and allegories of unity and resilience.
- Urban-environmental approach was applied to evaluate the aesthetic and psychological influence of murals on urban space, particularly in cities destroyed or damaged by hostilities.

- Empirical observation involved the qualitative study of specific murals in Kyiv, Kharkiv, Odesa, Rivne, and other cities, focusing on their thematic content and social reception.

The integration of these methods ensured a multi-dimensional understanding of street art as a reflection of societal transformation. It enabled the author to consider not only artistic forms but also the broader humanitarian function of murals in reconstructing collective identity and supporting psychological recovery in post-war Ukraine. The chosen methodological complex thus reveals street art as a dynamic medium that unites cultural memory, civic activism, and spatial renewal.

Literature Review

The study of street art as a phenomenon of modern culture has been actively developed in Ukrainian and international scholarship over the last decades. Researchers have examined the historical, aesthetic, and socio-cultural dimensions of muralism and graffiti as integral elements of urban transformation.

The first systematic explorations of graffiti in Ukraine appeared in the early 2000s, when scholars such as Chernyuk and Malinovska (*2007*) conceptualised graffiti as a complex cultural phenomenon rather than an act of vandalism. Their work emphasised the communicative and symbolic nature of street inscriptions, which reflected the values, moods, and identity of youth culture in post-Soviet urban environments. This interpretation shifted academic focus from destructive to creative aspects of graffiti, marking the beginning of its recognition as an urban art form.

Further development of monumental and street art practices in Western Ukraine was analysed by Efimova (*2014*), who traced how modern artists adapted international aesthetic trends within Ukrainian architectural contexts. Her research highlighted the synthesis of artistic innovation and local identity, demonstrating how monumental art can harmonise the visual environment of cities and enrich their cultural space.

A particularly significant contribution to the study of street art during times of social transformation belongs to Hrytsyuk (*2015*; *2019*). In her earlier work, she explored socio-political graffiti of the Revolution of Dignity, interpreting it as a spontaneous artistic reaction to civic protest and as a form of collective expression of freedom. Later, she systematised the historiography of Ukrainian wall painting, noting its evolution from marginal graffiti to institutionalised art practices integrated into cultural policy. Hrytsyuk's studies revealed that street art had become a legitimate medium for articulating national values and collective emotions.

The issue of preserving and reinterpreting Soviet monumental heritage was addressed by Ladan (*2008*), who analysed mosaics as a means of embodying post-avant-garde ideas in architecture and design. Ladan's findings are particularly relevant to the current discourse on the coexistence of Soviet mosaics and contemporary murals, raising ethical and aesthetic questions about restoration versus replacement. These debates echo in many Ukrainian cities where the visual memory of the past intersects with new patriotic and humanistic imagery.

Shylo and Ivashko (*2016*) examined the relationship between monumental art and street art in modern urban environments, focusing on how these forms influence urban aesthetics and identity. They argued that the transformation of street art from an underground subculture into

a recognised artistic and urban-planning practice reflects a broader process of social democratisation and the inclusion of public space in cultural dialogue.

The phenomenon of street art as a manifestation of contemporary artistic consciousness was comprehensively explored by Miro (*2018*). She described it as a hybrid field combining visual experimentation, social commentary, and civic activism. Miro highlighted that murals occupy a unique position between traditional fine arts and mass culture, transforming urban surfaces into symbolic narratives that convey social and emotional experience.

Finally, Simonov et al. (*2022*) analysed the practical implementation of street art projects in Ukraine, using the example of Siverskodonetsk. Their research demonstrated how muralism contributes not only to aesthetic renewal but also to socio-economic revitalisation, attracting tourism and community engagement. This empirical evidence supports the view that murals are an effective tool for urban rehabilitation and civic identity formation, particularly relevant in the post-war context.

In summary, the reviewed scholarship confirms that Ukrainian street art has evolved into a mature and multifaceted phenomenon at the intersection of visual culture, civic communication, and spatial regeneration. The literature underlines its dual function—as an artistic medium and as a sociocultural instrument of reconstruction and national resilience during periods of political upheaval and war.

Results

Most cities in Ukraine, where asphalt, grey, dark grey, and blue-grey colours are mainly used for painting the facades of houses, and insulation of the same colours is used for insulating apartments. As a result, already nondescript facades age over time, become unfriendly, and have a gloomy appearance, especially with the mass use of the so-called "patchwork" insulation. Ukrainian, especially industrial, cities have faceless buildings located both in the centre and on the periphery of the city. Such buildings and structures become a springboard for the birth of a new art—street art. Walls and roofs become a canvas for young artists who want to share their thoughts, prompting the viewer to think about the actual or eternal. Artworks by street artists help add charm to nondescript high-rise buildings, making them an object of aesthetic delight. Increasingly, it was possible to see drawings of street artists at the ends of houses, which were made at the order of the administration. It is worth noting that all this was before the war, but we hope that the development of this art will shine with brighter colours after the de-occupation of cities and the end of hostilities.

After the end of hostilities, it is necessary to legalise street art and grant more creative freedom, as well as special preference to young people. In such cases, murals can be used not only as decorative elements on attractive facades and walls, but also for the development of this type of street art in public spaces. Ukraine has experience in developing murals since 2014, when local authorities invited street artists from all over Ukraine to paint their drawings in designated locations (*Simonov et al., 2022*). There is a possibility that we will see the same practices in the post-war cities of Ukraine, especially in the occupied ones.

Murals have tremendous commercial potential. They hide building defects, actualise social problems, and convey key ideas to the target audience. At the same time, murals remain within the realm of art and do not devolve into mere advertising. In modern art history, mural art is a

form of street art, a legal artistic expression on the outer walls of houses in urban spaces for aesthetic purposes.

Muralists strive to express something symbolic in their works in an artistic way. In recent years, there has been a significant surge in street art: Ukrainian street artists have gained recognition not only in Ukraine but also worldwide. Citizens are enthusiastic about the newly created murals, and the city authorities have begun to invite street artists to collaborate. Street art in Ukraine has taken a place somewhere on the border between socio-political statements and contemporary art. This type of art often sparks heated discussions in society, but fails to leave anyone indifferent (*Miro, 2018*).

Street wall art is an indicator of moods, experiences, views and interests of modern society and is an integral part of the urban landscape, an attempt to make urban space more attractive and contribute to its harmonisation (*Hrytsyuk, 2015*; *Hrytsyuk, 2019*). Contemporary street art is focused not so much on the future as on the present. This type of activity attracts investment, promotes tourism development, and transforms dangerous and impoverished neighbourhoods into affluent and prestigious areas. This is a powerful tool for social change, and cities have become full-fledged canvases for him.

Art, transferred from a single skilfully executed canvas in a museum exposition to the wall of a modern high-rise building and with the help of aerosol cans, receives a different filling. Passing by city streets, you can see how huge, picturesque images—the so-called "murals"—appear more and more often on the blank facades of houses. This is evidence that spontaneous street art was gradually "civilised" and organically included in the urban strategy of harmonisation and modernisation of urban space (*Shylo & Ivashko, 2016*; *Efimova, 2014*).

Ukrainians are renowned for their creativity and innovative approach to every situation. In particular, since the beginning of the full-scale war, many tracks, memes, and patriotic drawings have appeared. The murals that adorn houses in almost every city have become mainly symbolic. Despite critics despising street paintings on houses, mural creators argue that it is a new art form that gives voice to those whose voices are not heard. Therefore, in this way, artists express their attitude towards the war waged by Russia against Ukraine, react to individual events, or support the people who are going through a difficult stage in Ukraine's history. In addition, they often utilise their creativity to support the Armed Forces of Ukraine by placing QR codes with links to fundraisers near them.

After February 22, 2022, murals can be divided into several main themes:

1. Honouring heroes are the Armed Forces of Ukraine, doctors, volunteers and others.
2. Memory of the dead is civilians and military.
3. Symbols of freedom are the trident, the Ukrainian flag, and the towels.
4. Calls for unity and victory are images of united hands in the colours of the Ukrainian flag.

During the war, murals appeared in almost every city, covering the whole of Ukraine geographically. The main centres are Kyiv, Dnipro, Odesa, and Mykolaiv, where numerous murals adorn houses damaged by shelling. There are murals dedicated to the soldiers of the Armed Forces of Ukraine in Lviv, Ternopil and Uzhhorod. There are murals about the invincibility of the city in Kharkiv. Irpin, Bucha, and Borodyanka are murals in memory of the victims of the occupation.

Famous examples:

"Girl in a Bulletproof Vest" in Kyiv, a symbol of the invincibility of Ukrainian women.
"Angels of Azovstal" are murals dedicated to the defenders of Mariupol.
"Flowers on the Ruins" in Irpin and Borodyanka, artists painted flowers on shelled buildings.
"Bird" is a mural in honour of the paramedic singer "Bird" from Azovstal.

The reason for the creation of murals is also the fact that in Ukrainian cities, there are still many images from Soviet times that should have been painted over a long time ago. Murals began to be created by both teams of artists and individual artists. Many Ukrainian cities have long suffered from abandonment, so the appearance of such elements is significant.

The centre of Khmelnytskyi is decorated with a mural "Ukraine Will Win!". It depicts a heroic Ukrainian woman with a sword in her hands and a stork's wing instead of an arm. A Ukrainian woman with a sword in her hands symbolises the readiness to fight and repel any enemy. The Patriotic mural "Ukraine Will Win!" is a symbol of the independence and invincibility of the Ukrainian people. There is the mural "Ukraine Will Win!" (*Figure 1*).

An interesting mural was created during the battles for the liberation of the cities of Bucha and Irpin. The artist depicted on the wall the hands of a soldier trying to sew the flag into one whole. This is an action that symbolises the return of Ukraine's territorial integrity. There is the mural "Ukrainian Soldier Stitching the Flag" (*Figure 2*).

In Ukraine, there is a project called "Cultural Landing". As part of this initiative, Ukrainian artists have already left their murals in the de-occupied territories of the Kharkiv, Mykolaiv, and Kherson regions.

Outstanding are the wall works of Ukrainian artists, symbolising the intolerance of the Ukrainian people to violence of any kind. The most famous mural of the city of Rivne is called "The Beauty Will Not Tolerate" (*Figure 3*). It depicts a girl with a machine gun, which symbolises Ukraine. The work is significant and aimed at strengthening the morale and psychological state of the Ukrainian military and people from occupied territories.

The heroes of murals can also be children. In the city of Kherson, there is a mural "Russia Is NEVER Here!" (*Figure 4*). The mural depicts a girl erasing the coat of arms of Russia—a golden double-headed eagle—and the inscription: "Russia Is NEVER Here". The drawing was depicted on the wall of one of the residential high-rise buildings as a symbol of the clear civic position of the citizens and as a sign that no crime will go unpunished.

In 2023, a mural dedicated to air defence forces and Ukrainian energy workers was unveiled in Kyiv. The mural received the symbolic name "Defenders of Light" (*Figure 5*). The winter of 2022–2023 has become a real challenge for energy workers. The enemy tried to plunge the country into darkness. However, the occupiers failed, so the idea arose to pay tribute to the defenders of light: every air defence soldier who defends the sky around the clock, and to every energy worker who restores light after massive attacks and hits on energy facilities. The mural depicts a soldier watching over the Ukrainian sky from the air, and an energy worker prepared to repair power grids in the event of damage, all in a matter of seconds. They are shown against the background of evening Kyiv, in which, thanks to their joint work, there is light in people's homes.

In 2018, muralists in Ivano-Frankivsk decorated the concrete walls of a residential building near the trolleybus stop. This is the mural "Hutsulka with a Laptop—Past and Present" (*Figure 6*). This mural holds a specific sacred meaning, which is that, despite the active development of

IT technologies, Ukrainian traditions remain our national treasure. The mural depicts a woman of the past with elements of progressive modernity. In their painting, the artists harmoniously combined the authentic beauty and interactivity of modern technologies.

Here, we see a certain correspondence between the mural "Hutsulka with a Laptop" and the mural "Defenders of Light", as the current events unfolding in Ukraine often limit our access to modern equipment, requiring the work of military and energy personnel. If it were not for the protection of these people, it would be impossible to work with modern technologies, without which most Ukrainians cannot imagine their lives.

Discussion

The findings demonstrate that modern Ukrainian street art plays a pivotal role in reimagining urban identity during wartime and post-war reconstruction. Murals have transformed from spontaneous expressions of youth culture into instruments of civic communication, memory preservation, and emotional healing. Their emergence on damaged buildings symbolises both physical and moral restoration. As noted in the research, Ukrainian muralism now bridges the gap between traditional national symbols and contemporary visual language, forming a unique code of resilience and hope.

The discussion highlights several key dimensions of this transformation. First, the aesthetic dimension—street art revitalises grey, monotonous post-industrial spaces by integrating colour, symbolism, and emotion into architectural surfaces. This contributes to the creation of an inclusive and spiritually enriching urban environment. Second, the sociocultural dimension—murals foster solidarity, articulate collective grief and pride, and serve as a moral compass in times of uncertainty. By depicting heroes, volunteers, and victims, artists translate national trauma into shared visual narratives.

Third, the communicative dimension—street art functions as an open dialogue between artists and society. It transforms passive observation into active engagement, inviting reflection on the values of freedom, dignity, and resistance. The use of digital elements such as QR codes in murals represents the synthesis of art and technology, enabling citizens to contribute to charitable initiatives or educational projects.

Moreover, street art has become a tool of cultural diplomacy. International recognition of Ukrainian murals enhances the country's visibility and reshapes its global image from victimhood to resilience and creativity. The cooperation between artists, municipalities, and civic groups indicates the institutionalisation of this art form, which now occupies an official place in urban design strategies.

However, challenges remain: the preservation of murals in war-affected areas, the risk of over-commercialisation, and the need for legal frameworks ensuring artists' rights and authenticity. Despite these obstacles, Ukrainian street art continues to evolve as a living chronicle of national rebirth.

Thus, the discussion confirms that murals have moved beyond decorative function to become instruments of socio-cultural reconstruction. They visualise the emotional energy of the nation, embodying both memory and aspiration, and transforming Ukrainian cities into vibrant symbols of freedom and unity.

Conclusion

The rapid development of modern engineering needs of the city is inextricably linked with its visual component. It is in this area that the synthesis of visual art with functional tasks takes place, allowing the solution of not only innovative issues and the combination of new technological techniques, but also enabling the perception of the urban environment as a modern, comfortable, and emotional space. Elements such as murals can be not only an object of art, but also a centre of attraction for both locals and tourists, which will have a positive effect on the city's budget.

Since the beginning of martial law, a large number of murals have appeared in Ukraine, expressing social and political moods, as well as contributing to the formation of the national identity of Ukrainians. Murals during the war became more than just art. They are a reflection of the events taking place in Ukraine. The murals support morale, preserve the memory of heroism and suffering, and unite Ukrainians in a common desire for Victory.

Conventionally, the murals that have appeared in Ukraine recently they are mostly patriotic, which is a natural phenomenon, given the situation in Ukraine. These are symbols of the modern Ukrainian Renaissance. However, some murals reflect significant situations that Ukrainians experienced during the war, such as the constant blackouts that occurred both in winter and in summer. It was a complex situation that led to a production collapse, making people's lives extremely uncomfortable. Ukrainians literally had to fight for light. At the same time, some murals appeared before the war and symbolise the combination of progress and tradition.

Studies have shown that elements of street art are becoming increasingly modern and progressive. However, at the same time, they do not lose their humanity and actively inform ordinary citizens and guests from other countries about what is happening in Ukraine, as there are events that one needs not only to be aware of, but also to treat with respect.

Conflict of Interest

The authors declare that there is no conflict of interest.

References:

Chernyuk, S., & Malinovska, K. (2007). Graffiti as a cultural phenomenon. *Problems of the Theory and History of Architecture of Ukraine*, *16*, 200–207.

Efimova, A. V. (2014). Features of the implementation of current trends in art in urban spaces in Western Ukraine: Modern monumental art practices. *Ukrainian Culture: Past, Present, Ways of Development*, *20*(1), 286–291.

Hrytsyuk, O. (2015). Socio-political graffiti of the Revolution of Dignity (based on materials from Kyiv). *Ethnic History of the Peoples of Europe*, *45*, 130–136.

Hrytsyuk, O. (2019). Street wall painting as an object of research: Historiography and state of study. *Collection of Scientific Works "Ethnic History of the Peoples of Europe"*, *58*, 113–117.

Ladan, T. M. (2008). Mosaic as a means of embodying post-avant-garde ideas in design and architecture. *Contemporary Problems of Architecture and Urban Planning*, 35–54.

Miro, I. M. (2018). Features of street art as a phenomenon of modern art. *Culture and Modernity*, *2*, 261–266.

Shylo, O. V., & Ivashko, O. D. (2016). Monumental art and street art in modern urban space. Collection of Scientific Works, 2, 74–78.

Simonov, S. I. et al. (2022). Street art as a decoration of facades and walls of houses in Siverskodonetsk: Problems and prospects. *Collection of Scientific Papers "Ukrainian Academy of Arts"*, *32*, 36–40. https://doi.org/10.32782/2411-3034-2022-32-4

Tyurikova, O. M., & Pogorelov, O. A. (2016). Art design in the modern design practice of Designers of the Architectural Environment (DAS). *Problems of the Theory and History of Architecture of Ukraine*, *16*, 119–123.

Appendix

Figure 1. Patriotic mural "Ukraine Will Win!", Khmelnytskyi, Ukraine

Figure 2. Mural "Ukrainian Soldier Sewing the Flag", Kyiv, Ukraine

Figure 3. Mural "Beauty Will Not Tolerate", Rivne, Ukraine

Figure 4. Mural "Russia Is NEVER Here", Kherson, Ukraine

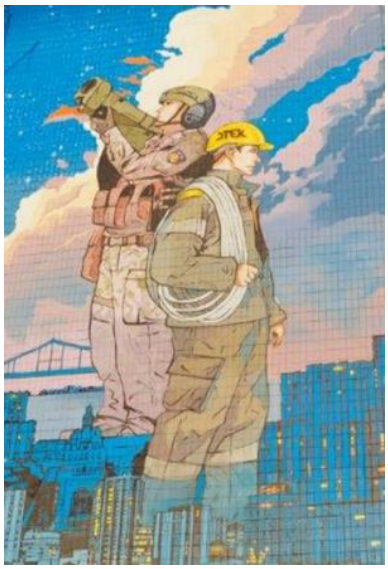

Figure 5. Mural "Defenders of Light", Kyiv, Ukraine

Figure 6. Mural "Hutsulka with a Laptop – Past and Present", Ivano-Frankivsk, Ukraine

Andrii V. Korzh [a][1]

Analysis of Biochemical Indicators of Iron Metabolism in Primary Allogenic Blood Donors [2]

Abstract: Currently, there is a significant shortage of donated blood and blood components worldwide. According to WHO recommendations, an adequate and reliable supply of safe and high-quality donated blood and blood components can only be achieved through regular voluntary unpaid donations. The study aims to examine the main biochemical indicators characterising iron metabolism in first-time allogeneic blood donors, in order to subsequently use them as reference values for comparative analysis in scientific research, as well as for developing practical recommendations concerning strategies for recruiting and retaining first-time voluntary unpaid blood donors. The methodological basis of this study was a systematic approach, which allowed for a comprehensive study and analysis of the biochemical indicators of iron metabolism in primary allogenic blood donors. The results obtained were used to develop practical recommendations for the Blood Centre of the Armed Forces of Ukraine regarding the strategy for attracting and retaining primary blood donors who make voluntary unpaid donations. Based on mathematical analysis, a positive correlation has been established between the indicators of secondary metabolic disorders in the examined donors and the main biochemical indicators of iron metabolism in first-time allogeneic blood donors, which may be used as reference values in conducting comparative analyses in future scientific studies.

Keywords: blood donors, donations, iron, biochemical parameters, primary allogeneic blood donors.

Abbreviations:

Ft is ferritin,

GMP is Good Manufacturing Practice,

SI is serum iron (concentration),

Tf is transferrin,

$TIBC$ is total iron-binding capacity,

TS is transferrin saturation,

$UIBC$ is unsaturated (latent) iron-binding capacity.

Introduction

According to the Association Agreement between Ukraine and the European Union, the European Atomic Energy Community and their Member States, our country embarked on the path of integration into the European Community. This, in particular, imposed requirements to review and reform the existing blood service in Ukraine, and envisaged the mandatory establishment of production in line with the requirements of GMP and the European Pharmacopoeia (*Vidborets & Derpak, 2022*; *Perekrestenko et al., 2014*; *Haidukova et al., 2014*).

The main provisions and principles were adopted as the basis for reforming the blood system in Ukraine, a process that continues successfully. Considering the general approaches to reforming transfusion medicine in Ukraine, in recent years the country has achieved the maximum possible implementation of organisational, methodological and legal approaches in

[a] Candidate of Medical Sciences (Ph.D.), Senior Lecturer, Department of Anesthesiology and Resuscitation, Faculty of Retraining and Advanced Training, Ukrainian Military Medical Academy. Kyiv, Ukraine.

accordance with European and global standards (*On Infectious Safety…, 2005*; *On Approval of the Procedure…, 2013*; *Guide…, 2020*).

The reform of the blood system in Ukraine has strengthened the position of transfusiology as an integral part of the healthcare system, which holds strategic significance for the state as a whole. Over the course of the reform, Ukraine's blood system has become more structured, acquired a truly systemic character, and now represents a synthesis of scientific achievements and practical work in the organisation and technology of blood collection, the production and use of blood components, the organisation, methodology and techniques of transfusion, and the protection of donor health (*Guide…, 2020*; *AABB Standards…, 2016*; *Fung et al., 2014*).

The main task of the blood service is to ensure equal access for the population of Ukraine to high-quality and safe components of donor blood in the required quantity (*On Infectious Safety…, 2005*; *Activities…, 2021*). The quality and safety of blood components refer to the compliance of donor blood, as the basis for the production of blood components, or components of blood directly collected from the donor (apheresis), which are supplied to consumers, with the legally established standards of quality and safety (*Fung et al., 2014*; *Blood Safety…, 2020*). Strict adherence to the established regulations and procedures for collection, testing, processing, storage, distribution, and transportation of donor blood and its components by the entities of the blood service serves as a guarantee of the quality and safety of blood components used for transfusion purposes, upon which the safety of recipients and the clinical effectiveness of transfusion directly depend (*Vidborets & Derpak, 2022*; *Perekrestenko et al., 2014*; *Haidukova et al., 2014*; *On Infectious Safety…, 2005*; *On Approval of the Procedure…, 2013*; *Guide…, 2020*; *Fung et al., 2014*; *Blood Safety…, 2020*).

Despite the obvious relevance of this issue for the blood service, few studies have been devoted to examining iron metabolism disorders in donors; the results presented are often contradictory, there is a lack of controlled studies and an insufficient evidence base, data regarding biochemical changes at different stages of participation in donation are not clearly defined, and the issues of post-transfusion reactions and complications, as well as the transmission of transfusion-transmitted infections, remain unresolved (*On Infectious Safety…, 2005*; *On Approval of the Procedure…, 2013*; *Activities …, 2021*; *Assessment…, 2020*; *Weiss et al., 2019*; *Vidborets et al., 2021*). This has prompted us to perform the present study.

The study aims to investigate the main biochemical parameters that characterise iron metabolism in first-time allogeneic blood donors, with a view to using them as reference values for comparative analysis in scientific research and for developing practical recommendations regarding strategies for recruiting and retaining first-time voluntary unpaid blood donors.

Methods and Materials

The methodological basis of this study was a systemic approach, which made it possible to comprehensively examine the biochemical indicators of iron metabolism in the blood of donors. We examined 135 first-time allogeneic blood donors from the Blood Centre of the Armed Forces of Ukraine.

According to the age classification (WHO, 2025), all the examined first-time donors were divided into three subgroups:

- young donors are 69 individuals (47 men and 22 women) aged 18 to 44 years;

- middle-aged donors are 47 individuals (35 men and 12 women) aged 45 to 59 years;
- older donors are 19 individuals (13 men and 6 women) aged 60 to 74 years (*Table 1*).

Thus, in the study group, the average age of the examined first-time donors was (37.87±1.33) years, with individual variations ranging from 20 to 59 years. The average age of male donors was (38.46±1.52) years, with individual variations from 20 to 59 years. The average age of female donors was (36.49±2.38) years, with individual variations from 22 to 56 years.

All 135 primary allogeneic blood donors were practically healthy and, based on the results of a questionnaire, specialist examination and determination of haemoglobin levels, were admitted to donate blood. The results of testing the donated blood for the presence of markers of transfusion-transmissible infections were negative. All donors were examined in accordance with the requirements of the "Procedure for Medical Examination of Blood Donors and/or Its Components", approved by Order of the Ministry of Health of Ukraine No. 385 dated August 1, 2005 (*On the Infectious Safety…, 2025*), as donors whose blood is used for the preparation of components, as well as in line with other applicable regulatory legal acts.

Before donating blood, the donors completed a questionnaire and underwent a medical examination by qualified specialists according to the requirements of the current "Procedure for Medical Examination of Blood Donors and Blood Components". For each donor, the haemoglobin content was determined (normal is not less than 135 g/L for men, not less than 125 g/L for women). Based on the examination results, the volume of blood donation was determined for each donor (there is 450 ml of the maximum permissible dose, excluding up to 40 ml of blood taken for testing).

After donation, the main biochemical parameters were determined in the donors' plasma, and screening for markers of transfusion-transmissible infections (HIV-1/2, hepatitis B, hepatitis C, syphilis) was performed. For the research, devices and reagents registered and certified for use in Ukraine were used. The devices underwent metrological control in accordance with the established periodicity.

The haematological parameters of peripheral blood were determined on automatic haematology analysers "Micros 60" (ABX, France) and "PCE-210" (ERMA, Japan), and the main biochemical parameters were measured on a semi-automatic biochemical analyser "STARDAST-MC-15" (DiaSys Diagnostic Systems, Germany). The iron content in serum was determined using the bathophenanthroline method. The $TIBC$ of serum was determined by saturating transferrin with trivalent iron. The unsaturated (latent) iron-binding capacity of serum was calculated as the difference between the total iron-binding capacity of serum and the serum iron content. The transferrin saturation coefficient was calculated as the ratio of serum iron content to the total iron-binding capacity of serum. The Tf content in serum was determined according to the total iron-binding capacity of serum. The ferritin content in serum was determined by the radioimmunoassay method. The obtained study results were processed using methods of variational statistics.

Literature Review

The development of modern transfusion medicine and donor safety systems is grounded in the convergence of international standards, national regulations, and biomedical research

addressing blood quality, donor health, and iron metabolism. The AABB Standards for Blood Banks and Transfusion Services (*2016*) and the AABB Technical Manual (*Fung et al., 2014*) remain key global references, establishing frameworks for blood component preparation, donor selection, and infection control. Similarly, the Guide to the Preparation, Use and Quality Assurance of Blood Components (*2020*) reflects European best practices harmonising quality assurance and haemovigilance protocols across member states.

At the national level, Ukraine has progressively aligned its blood service system with international guidelines through regulatory acts and monitoring programmes. The Orders of the Ministry of Health of Ukraine on infectious safety (*On Infectious Safety…, 2005*) and screening procedures (*On Approval…, 2013*) formalised the control of transfusion-transmissible infections, while the Activities of Blood Service Institutions of Ukraine in 2020 report (*2021*) provided analytical data on donor dynamics, stock management, and epidemiological trends. These measures correspond to the WHO recommendations (*Assessment of Iron Status…, 2020*; *Blood Safety and Availability, 2020*) on blood safety, availability, and iron status assessment, confirming the integration of evidence-based practices into Ukrainian transfusion policy.

Academic research has significantly contributed to understanding donor physiology and long-term safety. Derpak (*2009*) presented early morphometric analyses of erythrocytes in regular donors, revealing adaptive changes in red blood cell structure. Later studies by Derpak and Vydyborets (*2019a*; *2019b*) expanded this line of research, introducing a pathophysiological substantiation of donation safety based on complex clinical, biochemical, and biophysical parameters. Their findings highlighted the need for dynamic monitoring of iron metabolism and haematopoietic response among active donors, particularly those with extended donation histories.

The relationship between blood donation and iron metabolism has been comprehensively discussed in the monograph Blood Donation and Iron Metabolism (*Vidborets & Derpak, 2022*), which synthesises Ukrainian and international data on post-donation iron recovery, ferritin regulation, and gender-specific responses. The authors' approach is consistent with Weiss, Ganz, and Goodnough's (*2019*) analysis of iron metabolism disorders and anaemia of inflammation, which contextualises donor iron depletion as part of broader metabolic and immune interactions. Complementary research by Chepurna and Vydyborets (*2022*) proposed diagnostic algorithms for detecting iron deficiency in donors, incorporating WHO's serum ferritin criteria (*Assessment of Iron Status…, 2020*) and emphasising preventive monitoring.

Beyond physiological parameters, sociological and organisational aspects of donation are explored by Perekrestenko et al. (*2014*), who examined Ukraine's donation capacity and demographic determinants affecting donor recruitment. Haidukova, Vydyborets, and Sergienko (*2014*) addressed the motivational and educational dimensions of donor engagement, providing methodological tools for blood service institutions. Their insights resonate with WHO's (*Blood Safety and Availability, 2020*) advocacy for sustainable donor mobilisation and self-sufficiency in national blood supplies.

Finally, recent contributions by Vidborets et al. (*2021*) underscore the persistent challenge of transfusion-transmissible diseases, especially in the context of emerging infections. These studies reinforce the systemic interdependence between clinical research, regulatory

frameworks, and educational initiatives aimed at ensuring both donor well-being and recipient safety.

In summary, the reviewed literature demonstrates a coherent scientific trajectory in transfusion medicine—ranging from cellular morphology to public health regulation—linking Ukrainian empirical evidence with global standards. The synthesis of international guidelines (AABB, WHO, EDQM) and domestic research forms the basis for developing integrated donor monitoring systems, aligning biomedical, epidemiological, and ethical dimensions of modern blood donation.

Results

All 135 first-time allogeneic blood donors were practically healthy and, based on the results of questionnaires, examinations by specialists and determination of haemoglobin content, were deemed eligible to donate blood. The results of the donated blood screening for markers of transfusion-transmissible infections were negative.

A detailed peripheral blood analysis was performed for all examined first-time allogeneic blood donors at the laboratory of the Blood Centre of the Armed Forces of Ukraine; the results are presented in the appendix (*Table 2*).

As can be seen from the data in Table 2, the mean haemoglobin concentration among the group of first-time allogeneic blood donors was 133.50±1.99 g/l.

The mean haemoglobin concentration among the male donors was 138.13±2.49 g/l, with individual variations ranging from 133 g/l to 143 g/l, whereas among the female donors it was 129.09±1.51 g/l, with individual variations from 123 g/l to 135 g/l. The haemoglobin concentration in male donors was higher than that in female donors ($p<0.001$).

The mean red blood cell (erythrocyte) count among the group of first-time donors was $(4.74\pm0.32)\times10^{12}$/l. Among the examined male donors, the mean count was $(5.06\pm0.51)\times10^{12}$/l, while among female donors it was $(4.43\pm0.13)\times10^{12}$/l, with individual variations in men from 4.3×10^{12}/l to 5.2×10^{12}/l, and in women from 4.0×10^{12}/l to 4.8×10^{12}/l. The erythrocyte count in male donors was higher than in female donors ($p<0.001$).

The mean leukocyte count in male donors was $(6.54\pm0.29)\times10^{9}$/l, with individual variations from 4.5×10^{9}/l to 8.6×10^{9}/l, whereas in female donors it was $(6.37\pm0.14)\times10^{9}$/l, with variations from 4.9×10^{9}/l to 8.0×10^{9}/l. Overall, in the group of first-time donors, the mean leukocyte count was $(6.45\pm0.21)\times10^{9}$/l.

The mean platelet count among the group of first-time donors was $(227.73\pm2.44)\times10^{9}$/l. Among male donors, the mean platelet count was $(241.18\pm2.54)\times10^{9}$/l, while among female donors it was $(213.55\pm2.35)\times10^{9}$/l, with individual variations in men from 202×10^{9}/l to 253×10^{9}/l, and in women from 190×10^{9}/l to 237×10^{9}/l.

As can be seen from Table 2, among the examined first-time allogeneic blood donors, we did not find a statistically significant difference in the mean leukocyte and platelet counts by sex ($p>0.05$).

Below is a definition of the main indicators characterising the state of iron metabolism in the bodies of first-time allogeneic blood donors.

The SI concentration and the $TIBC$ of serum were determined using the bathophenanthroline method. In determining $TIBC$, magnesium carbonate was used as the sorbent. The $UIBC$ was calculated as the difference between $TIBC$ and SI. TS with iron was determined as the ratio of SI to $TIBC$ multiplied by 100%. The Tf content was assessed based on $TIBC$. The determination of FN content in blood serum was carried out using the radioimmunoassay method. The data on the analysis of the main indicators of iron metabolism in the plasma and serum of the examined first-time allogeneic blood donors are presented in the appendix (*Table 3*).

As shown in Table 3, the mean level of SI in the group of first-time donors was (20.38 ± 2.10) μmol/l. Among the examined male donors, this indicator averaged (22.75 ± 1.33) μmol/l, with individual variations ranging from 17.25 to 24.40 μmol/l, whereas in female donors it averaged (18.02 ± 1.30) μmol/l, with individual variations from 16.27 to 21.24 μmol/l. The SH content in male donors was higher than in female donors ($p < 0.01$).

The $TIBC$ indicator in the group of first-time donors averaged (57.70±2.51) μmol/l. In the examined male donors, this indicator was (56.72±2.37) μmol/l, and (58.68±2.20) μmol/l in females, with individual variations in males ranging from 52.06 to 61.02 μmol/L, and from 54.83 to 62.03 μmol/l in females. $TIBC$ in female donors was higher than in male donors ($p<0.01$).

The $UIBC$ indicator in the examined male donors averaged (34.99±4.08) μmol/l, with individual variations from 28.03 to 43.34 μmol/l, and (39.98±3.54) μmol/L in females, with individual variations from 34.16 to 45.62 μmol/l. Overall, in the group of first-time donors, $UIBC$ amounted to (37.48±4.35) μmol/l. $UIBC$ in female donors was higher than in male donors ($p<0.01$).

The iron TS indicator in the group of first-time donors averaged (34.80±4.93)%. In the examined male donors, this indicator averaged (36.58±4.74)%, and (33.02±3.63)% in females, with individual variations in males ranging from 28.62 to 46.11%, and from 26.39 to 38.31% in females. TS in male donors was higher than in female donors ($p<0.01$).

The Tf content in the group of first-time donors averaged (2.24±0.12) g/l. In the examined male donors, this indicator averaged (2.22±0.11) g/l, and (2.25±0.13) g/l in females, with individual variations in males ranging from 2.02 to 2.38 g/l, and from 2.14 to 2.50 g/l in females. The Tf content in female donors was higher than in male donors ($p<0.01$).

The FN content in the examined male donors averaged (24.98±2.10) μg/l, with individual variations from 20.17 to 30.60 μg/l, and (21.78±1.17) μg/l in females, with individual variations from 17.27 to 22.10 μg/l. Overall, in the group of first-time donors, FN content was (23.38±2.19) μg/l. The FN content in male donors was higher than in female donors ($p<0.001$).

Thus, the current research results have covered a larger cohort of first-time allogeneic blood donors compared to previous studies and can be used as control values for comparative analysis in future scientific research.

Discussion

The results obtained from the examination of 135 first-time allogeneic blood donors provide an important reference point for understanding baseline haematological and iron

metabolism parameters in individuals who have not previously experienced blood loss through donation. The overall normality of red blood cell, leukocyte, and platelet indices indicates that all donors were within the physiological norm before donation, confirming the effectiveness of preliminary medical screening and compliance with the eligibility criteria set by international standards such as those of the AABB (*2016*) and the European Directorate for the Quality of Medicines & HealthCare (*Guide…, 2020*). The absence of transfusion-transmissible infections among all participants further demonstrates the efficiency of the current donor selection and screening procedures established by the Ministry of Health of Ukraine (*On Infectious Safety…, 2005*; *On Approval…, 2013*).

The haemoglobin concentration results confirm the well-documented gender differences in haematological parameters. Male donors had significantly higher haemoglobin and erythrocyte counts compared with females ($p<0.001$), which aligns with the findings of Derpak and Vydyborets (*2019a*; *2019b*) and Chepurna and Vydyborets (*2022*). These differences are primarily attributed to the influence of androgens on erythropoiesis, greater total blood volume, and lower physiological iron loss among men. The values obtained in this study (mean 138.13 g/l for men and 129.09 g/l for women) are consistent with global averages for healthy adults reported by Weiss, Ganz, and Goodnough (*2019*). Importantly, no deviations were found that would indicate latent anaemia or pre-existing haematological abnormalities, suggesting that the selection criteria applied to first-time donors effectively ensure a high level of biological safety.

The mean leukocyte and platelet counts did not differ significantly between sexes, which corroborates the reference data presented by the AABB Technical Manual (*Fung et al., 2014*). This stability indicates the absence of acute inflammatory or infectious processes and supports the assumption that haematopoietic balance was maintained across the study cohort. These results may serve as a normative reference for Ukrainian donor populations, considering local dietary and environmental factors that can influence haematological variability.

A detailed assessment of iron metabolism markers reveals physiologically plausible gender-specific distinctions. The significantly higher serum iron (SI), transferrin saturation (TS), and ferritin (FN) levels among men ($p<0.01–0.001$) compared with women reflect a well-established biological trend related to menstrual blood loss and differences in iron storage capacity. Conversely, higher total iron-binding capacity (TIBC), unsaturated iron-binding capacity (UIBC), and transferrin (Tf) levels in women indicate an adaptive response to relatively lower body iron stores. These findings are in full agreement with WHO recommendations (*Assessment of Iron Status…, 2020*) for evaluating iron status by ferritin levels and align with data from Vidborets and Derpak (*2022*), who emphasised the diagnostic importance of such indicators in assessing donor readiness and preventing iron deficiency after repeated donations.

Notably, the mean ferritin level among female donors (21.78 μg/l) was close to the lower limit of the normal range (20–200 μg/l), highlighting a potential vulnerability of women to iron depletion even before their first donation. This observation supports international evidence (*Weiss et al., 2019*) indicating that premenopausal women are more susceptible to developing latent iron deficiency after repeated donations. Therefore, the current results underline the necessity of implementing preventive monitoring of iron metabolism in female donors, especially those with marginal ferritin levels before their first blood donation.

In comparison with previous Ukrainian studies (*Derpak, 2009*; *Perekrestenko et al., 2014*), the present research expands the sample size and provides a more detailed biochemical characterisation of iron homeostasis. The use of both classical (bathophenanthroline) and immunoassay methods ensured a high degree of analytical precision, while the inclusion of both genders in statistically balanced groups allowed for a meaningful comparative analysis. These methodological advantages strengthen the validity of the findings and offer reliable control values for subsequent longitudinal studies on regular donors.

The obtained results have practical significance for optimising donor management and blood service operations. They confirm that most first-time donors begin the donation process with adequate iron stores and normal haematological parameters, which can serve as a baseline for post-donation monitoring. However, the demonstrated gender disparities in iron status justify differentiated preventive recommendations, including dietary counselling, iron supplementation, or adjusted donation frequency for women. This approach is consistent with WHO's (*Blood Safety and Availability, 2020*) and AABB's (*2016*) strategic emphasis on maintaining donor health and preventing iron depletion as part of sustainable blood safety programmes.

In conclusion, this study contributes to the refinement of national reference values for haematological and biochemical indicators among first-time allogeneic donors. The observed parameters align with global physiological norms, validate current screening standards, and highlight the need for gender-sensitive strategies in donor health monitoring. Future research should focus on longitudinal tracking of repeated donors to assess post-donation recovery dynamics and identify early markers of iron deficiency, ensuring the long-term safety and sustainability of the donor pool in Ukraine.

Conclusion

Based on mathematical analysis, a positive correlation has been established between indicators of secondary metabolic disturbances in the examined donors and the main biochemical parameters of iron metabolism in primary allogeneic blood donors. These parameters can be used as reference values for comparative analysis in further scientific studies. The obtained results are recommended for use in developing practical guidelines regarding strategies for recruiting and retaining primary allogeneic blood donors who provide voluntary unpaid donations.

A promising direction is the search for new additional diagnostic criteria for iron metabolism disorders in primary allogeneic blood donors, as well as the study of secondary metabolic disturbances accompanying its deficiency.

It has been determined that when allowing subsequent donations, the levels of iron metabolism indicators in the plasma and serum of primary allogeneic blood donors—particularly ferritin—are worth considering. The results of the conducted studies allow for the formation of a risk group of blood donors based on informative biochemical characteristics of iron metabolism.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

AABB Standards for Blood Banks and Transfusion Services (30th ed.). (2016). Bethesda, Maryland: AABB Press.

Activities of Blood Service Institutions of Ukraine in 2020: Reference Book. (2021). Ministry of Health of Ukraine, National Academy of Medical Sciences of Ukraine, State Institution "Institute of Haematology and Transfusiology of the National Academy of Medical Sciences of Ukraine". Kyiv: DIA LLC. (In Ukr.). [Діяльність закладів служби крові України у 2020 році: довідник. МОЗ України, НАМН України, ДУ «Інститут гематології та трансфузіології НАМН України». К: ТОВ «ДІА», 2021.]

Assessment of Iron Status in the Human Body by Serum Ferritin Level. WHO recommendation. (2020). Genewa. https://www.who.int/publications/i/it em/9789240000124

Blood Safety and Availability. (2020). WHO. https://www.who.int/news-room/factsheets/detail/blood-safety-and availability

Chepurna, A. V., Vydyborets, S. V. (2022). Diagnostics of iron deficiency of blood donors. *Modern Enegineering and Innovative Technologies*, *23*(1), 77–87. https://doi.org/10.30890/2567.5273.2022-23-01-012

Derpak, Y. Y. (2009). Morphometric analysis of red blood cells in regular blood donors. *Actual Issues of Medical Science and Practice: Collection of Scientific Works*, *76*(1), 2, 108–113. (In Ukr.). [Дерпак, Ю. Ю. Морфометричний аналіз еритроцитів у регулярних донорів крові / Ю. Ю. Дерпак // Актуальні питання медичної науки та практики: збірник наук. праць. — 2009. — № 76(1). — Т. 2. — С. 108–113. Запоріжжя.]

Derpak, Y. Y., & Vydyborets, S. V. (2019a). Patho physiological substation of donations safety based on donors' clinical, laboratory, morphologic, biochemical and biophysical blood test results. In *Countties: Comparative analysis: Collective monograph* (pp. 62–88). Riga: Baltija Publishing.

Derpak, Y. Y., & Vydyborets, S. V. (2019b). Pattern of active blood donors donating for more than 10 years based on the results of laboratory, morphologic, biochemical and biophysical tests of peripheral blood. *Wiad. Lek.*, *12*(I): 2344–2347. https://doi.org/10.36740/Wlek201012144

Fung, M. K., Crossman, B. J., Hillyer, C. D., & Westhoff, C. M. (Eds.). (2014). *AABB Technical Manual* (18th ed.). Bethesda, Maryland: AABB Press.

Guide to the Preparation, Use and Quality Assurance of Blood Components: Recommendation No. R(95) 15 (20th ed.). (2020). European Directorate for the Quality of Medicines & HealthCare. Strasbourg.

Haidukova, S. M., Vydborets, S. V., & Sergienko, O. V. (Eds.). (2014). Donation: Attracting blood donors and its components: Textbook. Kyiv; Washington. (In Ukr.). [Гайдукова, С. М., Видиборець, С. В., Сергієнко, О. В. (ред.) Донорство: залучення донорів крові та її компонентів: навчальний посібник. Київ; Вашингтон: [б. в.], 2014: 199 с.]

On Approval of the Procedure for Screening Donated Blood and Its Components for Hemotransmisive Infections. (2013). Order of the Ministry of health of Ukraine No. 134 dated February 19, 2013. Verkhovna Rada of Ukraine. (In Ukr.). [Наказ МОЗ України від 19.02.2013 № 134 «Про затвердження Порядку скринінгу донорської крові та її компонентів на гемотрансмісивні інфекції» (зареєстровано в Міністерстві юстиції України 06.03.2013 за № 365/22897) / Верховна Рада України: офіційний веб-портал: Законодавство України]. http://zakon5.rada.gov.ua/laws/show/z0365-13

On Infectious Safety of Donated Blood and Its Components. (2005). Order of the Ministry of health of Ukraine No. 385 dated August 1, 2005. Verkhovna Rada of Ukraine. (In Ukr.). [Наказ МОЗ України від 01.08.2005 № 385 «Про інфекційну безпеку донорської крові та її компонентів» (зареєстровано в Міністерстві юстиції України 16.08.2005 за № 896/11176) / Верховна Рада України: офіційний веб портал: Законодавство України]. http://zakon3.rada.gov.ua/laws/show/z0895-05

Perekrestenko, P. M., Nazarchuk, L. V., Burkova, I. S., & Samus, V. M. (2014). Donation capacity of the population of Ukraine. *Hematology and Blood Transfusion*, *37*, 323–333. (In Ukr.). [Донороздатність населення України / П. М. Перехрестенко, Л. В. Назарчук, І. С. Буркова, В. М. Самусь // Гематологія і переливання крові. — 2014. — Вип. 37. — С. 323–333].

Vidborets, S., & Derpak, Yu. (2022). Blood donation and iron metabolism: monograph. Boston: Primedia eLaunch. (In Ukr.). [Видиборець С, Дерпак Ю. Донації крові і метаболізм заліза: моногра фія. Boston: Primedia eLaunch, 2022]. https://doi.org/10.46229/979-8 88831-933-8

Vidborets, S., Derpak, Yu., Kucher, O., & Goryainova, N. (2021). Transfusion-transmissible diseases. In *Trends in the development of medicine, biology and pharmacy: Collective monograph* (pp. 126–166). Boston: Primedia eLaunch. (In Ukr.). [Видиборець С, Дерпак Ю, Кучер О, Горяінова Н. Трансфузійно-трансмісивні захворювання. Trends in the Development of Medicine, Biology and Pharmacy: Collective Monograph. Boston: Primedia eLaunch, 2021. — С. 126–166]. https://doi.org/10.46299/ISG.2021.M ONO.MED.1

Weiss, G, Ganz, T, & Goodnungh, L. T. (2019). Iron metabolism and its disorders. Anemia of inflammation. *Blood*, *133*(1), 40–50. Available at: https://doi.org/10.1182/blood 201806-856500

Appendix

Table 1. Age structure of examined primary allogeneic blood donors depending on age (n=125)

Age group of donors	Men (n)	Women (n)	Total (n)
Youth, 18–44 років	47	22	69
Average, 45–59 років	35	12	47
Old, 60–74 років	13	6	19
Total:	95	40	135

Table 2. peripheral blood parameters in primary allogeneic blood donors (M+m)

Indicator, unit of measurement	All donors (n=135)	Men (n=95)	Women (n=40)	Достовірність різниці (p)
Hemoglobin concentration, g/l	133,50±1,99	138,13±2,49	129,09±1,51	p<0,001
Number of red blood cells, 10^{12}/l	4,74±0,32	5,06±0,51	4,43±0,13	p<0,001
Кількість лейкоцитів, 10^9/l	6,45±0,21	6,54±0,29	6,37±0,14	p>0,05
Кількість тромбоцитів, 10^9/l	227,73±2,44	241,18±2,54	213,55±2,35	p>0,05

Note: p is reliability of the difference between indicators depending on gender.

Table 3. indicators of iron metabolism in plasma and serum of primary allogeneic blood donors (M±m)

Indicator, unit of measurement	All donors (n=135)	Men (n=95)	Women (n=40)	Reliability of the difference (p)
SI, mmol/l	20,38±2,10	22,75±1,33	18,02±1,30	p<0,01
$TIBC$, mmol/l	57,70±2,51	56,72±2,37	58,68±2,20	p<0,01
$UIBC$, mmol/l	37,48±4,35	34,99±4,08	39,98±3,54	p<0,01
TS, %	34,80±4,93	36,58±4,74	33,02±3,63	p<0,01
Tf of serums, g/l	2,24±0,12	2,22±0,11	2,25±0,13	p<0,01
FN of serum, mcg/l	23,38±2,19	24,98±2,10	21,78±1,17	p<0,001

Note: p is reliability of the difference between indicators depending on gender.

Olena I. Stepanenko [a][4]

The Use of Innovative Technologies in ESP Instruction for IT Students within the Framework of Open Education [3]

Abstract: The article explores the integration of innovative technologies in teaching English for Specific Purposes to students majoring in Information Technologies. It argues that traditional approaches are inadequate in addressing the demands of the digital era. Therefore, the adoption of educational innovations is essential to ensure the relevance and effectiveness of English for Specific Purposes instruction. The subject of the study is the integration of innovative digital technologies and Open Education principles into ESP teaching for IT students. The object of the study is the process of teaching English for Specific Purposes to IT students in higher education. The study focuses on technologies that aligned with the principles of Open Education, including artificial intelligence and chatbots, virtual and augmented reality, learning management systems, gamification, and international educational initiatives — particularly the Collaborative Online International Learning format. The study employs a combination of methods, including theoretical analysis of scientific literature, policy documents, and empirical studies on ESP, Open Education, and digital technologies; comparative analysis of technological tools and pedagogical approaches relevant to ESP instruction; content analysis of open educational resources and platforms used in ESP; case study method for examining practical implementation of innovative technologies (e.g., AI tools, VR/AR, COIL); and generalisation and synthesis for formulating practical recommendations for integrating technologies into ESP curricula. The article emphasizes the importance of Open Education as both a philosophy and a methodology that promote accessibility, co-creation of knowledge, and flexible learning. Special attention is given to the SAMR model as a framework for the implementation of technology — from substitution of traditional methods to their complete redefinition. The author illustrates how these technologies can be used to create a learning environment focused on collaboration, critical thinking, and intercultural communication. The study also identifies the challenges associated with technology integration, including digital inequality of learners, teacher resistance, pedagogical inconsistency, and issues issues related to copyright and licensing. Despite these obstacles, the article highlights the transformative potential of educational technologies to enable personalized learning, foster global competencies, and enhance the authenticity and sustainability of educational programs. The article concludes with practical recommendations for further integration of innovations in the line with open pedagogy and the needs of the IT industry.

Keywords: English for Specific Purposes, IT students, innovative technologies, Open Education, digital tools, SAMR model, Artificial Intelligence, gamification, virtual and augmented reality, Collaborative Online International Learning.

Abbreviations:

AI is artificial intelligence;

COIL is Collaborative Online International Learning;

ESP is English for specific purposes;

IT are information technologies;

LMS is Learning Management System;

MOOCs are Massive Open Online Courses;

[a] Candidate of Pedagogical Sciences (Ph.D.), Associate Professor, Educational and Scientific Institute of Philology, Taras Shevchenko National University of Kyiv. Kyiv, Ukraine.

OER is open educational resources;
$SAMR$ is substitute, augment, modify, and redefine;
$TPACK$ is technology of pedagogical content knowledge.

Introduction

The integration of digital technologies into education significantly influences the pedagogical practices across various disciplines, including ESP (*Herlina & Said, 2022*). The increasing utilization of digital tools within educational environment has created new opportunities to enhance the quality of language instruction, particularly in ESP courses for IT students. ESP is an educational field designed to address the specific linguistic and communicative requirements of students within professional or academic contexts (*Freeman et al., 2015*). The global nature of the technology sector requires not only technical expertise but also advanced English communication skills. As IT professionals are increasingly expected to engage in international collaboration, access global research, and contribute to worldwide innovation, proficiency in English within a professional context becomes indispensable. However, traditional pedagogical approaches to ESP instruction often fall short of addressing the contemporary needs of students who are increasingly immersed in digital technologies in both their personal and professional spheres. The growing reliance on digital technologies in daily life profoundly impacts teaching and learning methodologies (*Rachmawati et al., 2020*). Tools such as online learning platforms, educational applications, virtual classrooms, and multimedia resources have not only revolutionized the delivery of educational content but also enhanced student engagement and collaboration. Concurrently, the transformation of educational environments through digitalization and globalization has expedited the incorporation of innovative technologies into ESP teaching and learning. From artificial intelligence-based tools to immersive virtual learning environments, these technologies hold the potential to enhance language acquisition, foster student autonomy, and simulate real-world professional communication tasks pertinent to the IT industry.

Open Education, characterized by its focus on accessibility, collaborative knowledge creation, and the unrestricted exchange of educational resources, provides a robust framework for the modernization of ESP. By integrating the objectives of ESP with the principles and tools of Open Education, educators can develop a dynamic, technologically enhanced learning environment tailored to the linguistic and professional needs of students specializing in IT.

The subject of the study is the integration of innovative digital technologies and Open Education principles into ESP teaching for IT students.

The object of the study is the process of teaching English for Specific Purposes to IT students in higher education.

The study aims to examine the types of innovative technologies most relevant to ESP for IT students in the framework of Open Education, underscore the significance of Open Education as a guiding philosophy, and present practical strategies for incorporating these technologies into ESP curricula.

To achieve the goal, it is necessary to solve the following tasks:

– identify and classify the types of innovative technologies applicable to ESP instruction for IT students;

- analyse the pedagogical potential of Open Education principles for enhancing ESP curricula;
- explore the role of digital tools in fostering student engagement, autonomy, and professional communication competence;
- evaluate practical models of technology integration into ESP instruction, with specific reference to IT-related contexts.
- develop recommendations for educators on effective strategies for incorporating innovative.

The study employs a combination of methods, including:

- Theoretical analysis of scientific literature, policy documents, and empirical studies on ESP, Open Education, and digital technologies.
- Comparative analysis of technological tools and pedagogical approaches relevant to ESP instruction.
- Content analysis of open educational resources and platforms used in ESP.
- Case study method for examining practical implementation of innovative technologies (e.g., AI tools, VR/AR, COIL).
- Generalisation and synthesis for formulating practical recommendations for integrating technologies into ESP curricula.

Methods

The research methodology was based on a combination of general scientific and specific methods, allowing for a comprehensive analysis of the integration of innovative technologies into ESP instruction for IT students within the framework of Open Education. At the general scientific level, theoretical and empirical methods were used to ensure a systemic understanding of the pedagogical and technological foundations of the study. Theoretical analysis included the examination of relevant scientific literature, policy documents, and empirical studies on digitalisation of higher education, English language teaching methodologies, and the principles of Open Education. This approach made it possible to generalise the current scientific discourse, identify existing gaps in research, and determine the conceptual basis for technology integration in ESP.

Comparative analysis was employed to contrast different technological tools and pedagogical approaches in ESP teaching, particularly focusing on their relevance and adaptability to IT-related contexts. This method facilitated the identification of the advantages and limitations of each technology—from artificial intelligence systems and learning management platforms to gamification and virtual learning environments—helping to determine their pedagogical effectiveness for ESP learners. Generalisation and synthesis were used to consolidate findings from various case studies, allowing the formulation of practical recommendations for integrating digital technologies into ESP curricula while preserving academic and methodological integrity.

Among empirical methods, content analysis was applied to evaluate the functionality and didactic potential of OERs, online platforms, and collaborative learning environments. The analysis covered the structure, accessibility, and degree of pedagogical interactivity of open

materials and systems, thus ensuring their compliance with the requirements of Open Education. The case study method provided opportunities for a deeper exploration of specific examples of implementing innovative technologies in ESP teaching. In particular, it analysed the use of AI and chatbots (ChatGPT, Replika, Grammarly), virtual and augmented reality tools, gamified environments (Kahoot!, Quizlet), and international collaborative models such as Collaborative Online International Learning (COIL). This method helped to highlight best practices and successful cases of integrating technology in higher education language programs.

In addition, modelling was used to conceptualise the process of technological integration according to the SAMR framework, which includes four levels—substitution, augmentation, modification, and redefinition. This model allowed the researcher to evaluate the degree of pedagogical transformation achieved through technology. Logical and systemic approaches underpinned the entire methodological design, ensuring the coherence of analysis, interpretation, and generalisation of the results. The combination of these methods made it possible to construct a holistic view of how digital tools, grounded in the philosophy of openness, contribute to developing innovative, interactive, and sustainable ESP instruction for IT students.

Literature Review

The literature review addresses the theoretical foundations, empirical evidence, and pedagogical implications of integrating innovative technologies into ESP instruction, with a focus on IT education and the Open Education paradigm. The rapid advancement of digital tools has transformed the structure and delivery of language education, stimulating academic interest in the intersection of technology, pedagogy, and professional communication (*Herlina & Said, 2022*; *Freeman et al., 2015*). Scholars agree that ESP, as a professionally oriented branch of English language teaching, must evolve to meet the communicative demands of the global digital economy, especially in fields such as programming, cybersecurity, and software engineering.

A significant body of research highlights that Open Education serves as both a methodological and philosophical foundation for integrating innovative technologies in language teaching (*Opening up Education, 2016*; *Kawachi, 2014*). It promotes accessibility, collaboration, and transparency through OERs, which enable instructors to adapt materials to specific professional contexts while maintaining inclusivity (*Allen & Katz, 2020*; *Krajka, 2018*). The European Commission's framework on Open Education further reinforces the necessity of creating flexible, technology-mediated learning environments that remove barriers to education and encourage cross-border collaboration (*Shaping Europe's Digital Future, 2020*). These approaches are consistent with UNESCO's vision of equitable access to knowledge and sustainable educational innovation (*Observatory…, 2011*).

Recent studies focus on AI and chatbots as key tools for enhancing language learning outcomes. Research demonstrates that AI systems—such as ChatGPT, Grammarly, or DeepL—facilitate interactive learning, adaptive feedback, and professional vocabulary acquisition in ESP contexts (*Bailey & Almusharraf, 2021*; *Lu & Zeng, 2025*). AI-based chatbots enable learners to engage in authentic professional communication while overcoming temporal and spatial barriers (*Hamzah et al., 2021*; *Silitonga et al., 2024*). Similarly, the work of Wang and

Petrina (*2013*) and Dashtestani and Stojković (*2015*) underscores the pedagogical benefits of integrating AI into ESP course design, stressing its potential for learner autonomy and increased motivation.

Another important research direction concerns virtual and augmented reality (VR/AR), which provides immersive, contextualised environments for language acquisition in professional settings. Stepanenko, Kokhan, and Mykhaylova (*2023*) as well as Krasnenko (*2024*) demonstrate that VR applications and speech-simulation tools (SpeakandImprove, SmallTalk2Me) enhance learners' communicative competence by replicating real-world IT scenarios. Furthermore, LMSs such as Moodle and Canvas have become essential infrastructure for online ESP education, providing mechanisms for collaboration, assessment, and open content integration (*Bradley, 2021*; *Chaw & Tang, 2018*). Their adaptability to blended learning environments fosters both learner autonomy and institutional scalability.

Gamification and game-based learning have emerged as effective motivational strategies in ESP teaching. Empirical research confirms that platforms like Kahoot!, Quizlet, and Duolingo foster engagement, creativity, and knowledge retention while aligning with learner-centred pedagogies (*Scott, 2024*; *Voshchevska et al., 2023*). The integration of gamified elements into ESP for IT students supports collaborative learning and cognitive activation, making language study both dynamic and interactive.

A distinct feature of Open Education is the COIL model, which supports intercultural and interdisciplinary learning through joint online projects (*Hackett et al., 2023*). Its use in ESP instruction enables students to develop communicative competence and global citizenship skills by participating in real-world problem-solving across linguistic and cultural boundaries. Studies conducted in Ukraine and Latin America demonstrate the effectiveness of COIL in enhancing motivation, critical thinking, and professional communication (*Stepanenko, 2025*).

Thus, the current literature converges on the idea that innovative technologies—artificial intelligence, VR/AR, LMSs, gamification, and COIL—transform ESP teaching into a multidimensional process that combines linguistic proficiency, digital literacy, and intercultural competence. The Open Education paradigm provides the conceptual and ethical framework for this transformation, ensuring accessibility, co-creation, and adaptability in modern language pedagogy.

Results

ESP in the Context of Open Education

In the digital era, the importance of ESP has grown, particularly in the IT industry where swift technological advancements and international collaboration are commonplace. Consequently, ESP courses are adapting to encompass not only language proficiency but also essential 21st-century skills like digital literacy, critical thinking, and intercultural communication. Instructional approaches have transitioned from conventional textbook-based methods to more interactive, technology-driven models that simulate real-world work environments and encourage active participation in problem-solving. Today, the integration of information technologies in education, especially in language learning, has advanced with the development of MOOCs, communities of practice, and OERs, along with tools such as LMSs, cloud

technologies, and artificial intelligence systems. These technological advancements and innovations are reflected in publications from journals focused on technology in language education, such as ReCALL (the European Association for Computer Assisted Language Learning Journal), CALL (Computer Assisted Language Learning Journal), CALICO (Computer Assisted Language Instruction Consortium Journal), and Language Learning and Technology Journal etc. These advances are also apparent in the European Commission's efforts to empower individuals with the use of digital technologies (*Shaping…, 2020*) and the initiation of additional EU-funded research and innovation projects, like the DC4LT (*DC4LT Consortium, 2019*).

Learning platforms, mobile applications, and artificial intelligence systems provide personalized and flexible opportunities for language acquisition. This shift indicates the increasing integration of ESP with educational technology, prompting educators to adopt novel pedagogical models and incorporate innovative solutions into ESP course development. Open Education is a philosophy and practice that advocates for broad access to learning opportunities, transparency in knowledge production, and collaboration across institutional and national boundaries. According to the European Commission, Open Education is defined as "a way of carrying out education, often using digital technologies. Its aim is to widen access and participation to everyone by removing barriers and making learning accessible, abundant, and customizable for all. It offers multiple ways of teaching and learning, building and sharing knowledge. It also provides a variety of access routes to formal and non-formal education, and connects." (*Opening up Education…, 2016*) It encompasses various components, including OER, open licensing, open pedagogy, and technological learning environments. Within the context of ESP, Open Education facilitates the development and dissemination of freely available materials tailored to specific professional fields, enabling educators to customize content to meet the diverse needs of their students.

The synergies between Open Education and ESP are particularly evident in the use of OER, such as open-licensed ESP textbooks, video tutorials, glossaries, corpora, and case-based learning modules. These resources not only reduce barriers to access, but also allow educators to create more relevant and authentic materials, especially for highly specialized fields such as IT. In addition, Open Education encourages collaboration between institutions, facilitating transnational projects and knowledge sharing—principles that are consistent with the global nature of the IT According to UNESCO (*2011*), the potential of information technology in education is crucial to equip educators in the growing information society with the tools they need to creatively influence teaching and learning, enabling them to meet the challenges of a disruptive environment and global progress towards a more demanding knowledge-based society (*Observatory…, 2011*).

In addition, digital tools make it possible to teach ESP outside the classroom. OER are learning materials that can be used in teaching and learning contexts according to the 5Rs (retain, reuse, revise, remix, or redistribute) and are recognized by all stakeholders as an invaluable means to allow inclusive and equitable gain to information and learning (*Kawachi, 2014*).

Teachers' willingness to use OER results from the possible opportunity to increase learning experiences and make learning more accessible for learners who cannot afford or access commercial textbooks or sources (*Allen & Katz, 2020*; *Krajka, 2018*). In her report to UNESCO,

Scott C. (*2015, p. 16*) emphasizes the role of educational technology in this transformation: edagogical innovation must equip learners with the skills and competencies to function in a digital culture, using media and informal pathways to enrich their learning and develop essential forms of literacy. Teachers will require meaningful support and time to exploit available resources and tools to create tailor-made learning experiences that are motivating and engaging, yet efficient, relevant and challenging.

Another major component of Open Education is COIL, which brings together students and teachers from different countries in joint virtual projects COIL is an educational method that has become a popular approach used to internationalize the curriculum and facilitate students' curriculum content and intercultural learning through collaboration (*Hackett et al., 2023*). COIL offers IT students real opportunities to use English in a professional environment, engage in intercultural communication, and develop teamwork skills—all in an open, digitally mediated environment.

Implementing Open Education principles in ESP teaching can lead to more inclusive and adaptive learning ecosystems. This enables both teachers and students to become co-creators of knowledge and increases the relevance of ESP curricula to the changing demands of the IT profession.

Types of Innovative Technologies Relevant to ESP for IT Students: Practical Implementation

Innovative technologies used in ESP courses are changing the way IT students acquire language skills and professional competencies. These technologies serve as both tools and environments for engaging, interactive, and student-centered learning. Let us look at the most influential categories of technological innovations that are currently transforming ESP for IT students.

It is worth noting that for meaningful integration of technology in ESP education, teachers should align learning objectives with the capabilities of digital tools. Instructional design models such as SAMR and TPACK provide teachers with structured approaches to integrate technology in pedagogically sound ways.

The SAMR model was used in our study. For example, in the ESP course for students, the use of technology took place at the following levels:

- Substitution: using Google Docs instead of paper for written assignments.
- Augmentation: activating artificial intelligence-based tools such as Grammarly for improved language feedback.
- Modification: running peer-reviewed blogs on cybersecurity topics using WordPress.

Redefining: running a COIL-based IT project with international colleagues using English as the language of collaboration (*Walsh, 2015*). By designing assignments that go through these stages, educators can go beyond superficial use of tools and provide transformative learning experiences.

Artificial Intelligence and Chatbots

The integration of chatbots into future ESP teaching strategies aims to transform traditional approaches by leveraging the interactive, personalized, and flexible capabilities of AI. AI and

chatbots are increasingly recognized as effective tools in ESP teaching (*Bailey & Almusharraf, 2021*), especially for vocabulary acquisition and interactive language practice. Recent research has shown several key benefits and implications of integrating AI chatbots into the EFL learning environment. First of all, the use of AI improves students' mastery of professional vocabulary. Experimental studies have shown that students who use AI chatbots (such as Dialogflow, Replika, Chat GPT) significantly outperform those who study in a traditional learning environment when it comes to learning ESP vocabulary.

Chatbots can be programmed to provide targeted vocabulary, synonyms, and concise explanations, making them highly adaptable to the specialized language needs of learners studying English for professional purposes (*Bailey & Almusharraf, 2021*).

AI tools can be used to create an interactive and engaging learning environment. Chatbots mimic natural conversations, allowing students to practice language in context and discuss meaning. D. J. Lu and Y. Zeng (*2025*) believe that teachers can use ChatGPT to create differentiated text samples that correspond to different levels of knowledge and learning needs in a heterogeneous classroom, allowing students to receive appropriate support. According to Lu D. J. & Zeng Y. (*2025, p. 17*), with appropriate prompts that specify factors such as language complexity and writing rules, teachers can adapt model texts to different educational contexts (e.g., secondary school or higher education) according to the requirements of the educational institution. In our opinion, this has a positive impact on developing both vocabulary and communicative competence in specific professional or academic fields

The interactive nature of chatbots increases student motivation, engagement, and participation, as students perceive the technology as easy to use and directly related to their learning goals. The integration of technology and ESP has been productive, and the application of technology in the field of ESP (*Wang & Petrina, 2013*). Dashtestani & Stojković (*2015, p. 533*) similarly recommended that ESP teachers try to use a wide range of technologies in their ESP courses to maximize student participation and engagement in language learning, and they should adopt positive attitudes towards the use of technology for students' learning.

One of the advantages of using chatbots in education is their availability on various platforms (e.g., Facebook, WhatsApp, Twitter), which makes them accessible for self-study, regardless of location. They help overcome the limitations of traditional classroom learning, such as time constraints, lack of individual attention, and limited access to native-speaking teachers.

Researchers (*Dashtestani & Stojković, 2015*; *Wang, 2015*) demonstrate that the integration of artificial intelligence and chatbots into ESP learning is not limited to vocabulary; there is potential to extend their use to other language skills and broader educational contexts. Current research shows that chatbots can complement or even transform the delivery of ESP courses, supporting the trend toward more technology-oriented, personalized, and flexible language education.

AI has revolutionized educational practices, enabling the emergence of intelligent feedback systems, adaptive learning platforms, and interactive language tools. AI-based language models such as ChatGPT, Grammarly, and DeepL can support those learning ESP by providing real-time assistance with technical writing, grammar correction, terminology clarification, and paraphrasing. D. J. Lu and Y. Zeng (*2025*) note in their study the success of using text samples

generated by ChatGPT, which can be a valuable feedback tool for improving the quality of texts written by students learning English as a foreign language in terms of content, organization, vocabulary, and grammar, and how useful ChatGPT-generated text samples are as a feedback tool (*p. 18*). In ESP English classes for IT specialists, tasks such as simulating technical interviews and question-and-answer sessions, instant explanations of subject-specific vocabulary, tasks using AI to compile project documentation and reports, and tasks involving communication practice in realistic contexts are useful.

Researchers (*Hamzah et al., 2021*; *Silitonga et al., 2024*) emphasize the significance of integrating technology with ESP to enhance course design and development. Tasks involving interaction that require negotiation of meaning appear to significantly aid learners in advancing their second language lexical development. A chatbot creates a stimulating atmosphere to encourage such encounters.

Virtual Reality and Augmented Reality

Virtual reality and augmented reality offer an immersive learning experience that simulates professional IT environments such as data centers, conference rooms, or virtual offices, where students can practice English in relevant scenarios. For example, participating in virtual meetings with avatars representing; navigating augmented technical manuals or diagrams; performing IT-related tasks that require following instructions in English. These technologies enhance situational learning, contextual vocabulary acquisition, and student engagement by providing rich, visual, and interactive settings. With the help of innovative technologies, namely virtual reality applications, IT students can not only watch videos about world-famous digital corporations, but also explore them virtually in pairs or groups: practice their speaking skills, share their impressions, and describe what they have seen (*Stepanenko et al., 2023, p. 259*). For example, students can learn about Microsoft Office in Hong Kong, Cisco. To develop foreign language communication skills, students can also use SpeakandImprove and SmallTalk2Me. These technologies allow users to hold conversations and evaluate speech according to several criteria. They test oral proficiency and help prepare for interviews and the oral part of the IELTS international exam (*Krasnenko, 2024*).

Learning Management Systems and Open Platforms

LMSs such as Moodle, Google Classroom, Canvas, and others play a central role in organizing and delivering ESP English language content. Thanks to integration with Open Educational platforms and plugins, LMSs are becoming powerful hubs for hosting ESP courses based on OER; tracking students' language progress; embedding tests, collaborative writing tasks, and expert assessment tools. In Open Education environments, LMS also facilitate access to repositories of ESP materials and enable their exchange between institutions and countries. This is confirmed by research on university students' perceptions of learning management systems in resource-constrained environments using the technology adoption model (*Bradley, 2021*; *Chaw & Tang, 2018*). Bradley (*2021*) presents a comprehensive analysis of how LMSs function as integral platforms for delivering online education, promoting learner autonomy, and fostering engagement through both synchronous and asynchronous modalities. According to Bradley (*2021, p. 86*), LMSs

support constructivist learning environments, encouraging collaborative learning and inquiry-based instruction grounded in the principles of student-centered education.

Gamification and Game-Based Learning

Gamification involves applying game elements to language learning, such as points, badges, leaderboards, and timed tasks, to increase motivation and knowledge retention. In English for IT students, this could take the form of:

- Terminology competitions based on cybersecurity or programming.
- Scenario-based games where students solve IT problems using English.
- Escape room simulations that include IT vocabulary and logic puzzles.

In addition, it is important to implement a system for tracking and recording student progress, which can be done using digital tools, online platforms, and applications that allow you to record scores, task completion levels, or other relevant metrics (e.g., Kahoot!, Quizlet, Duolingo, Wordwall, Minecraft—Education Edition, Wheel of Names, Classcraft, Flippity, GooseChase, Epic!, Seesaw, etc. (*Scott, 2024*). Platforms such as Kahoot!, Quizlet, and Wordwall offer customizable tools for gamifying both technical and linguistic content. An analysis of scientific sources indicates the use of a fairly large number of services for the implementation of gamification in the education system. Here are some of them that will be useful for teachers, educators, and scientific and pedagogical staff when teaching philological disciplines:

1. Kahoot! is a free online service for creating interactive educational games.
2. MinecraftEdu is an online simulator in which players can create game worlds from blocks and interact with other players.
3. Duolingo is a huge online community that combines the ability to learn a language online with a paid text translation service.
4. Coursera is an educational platform and social company that collaborates with leading universities to transform some of their programs into online courses that are free to access for anyone. The system contains many different courses, ranging from the humanities and arts to engineering and business. The courses are presented in the form of short video lectures on various topics and assignments, which are usually released weekly.
5. Quizlet is a game that helps test the level of knowledge and terminology of students.
6. Learningapps is a free online constructor. With its help, you can create interactive game tasks in any discipline. To do this, you just need to select a template and enter your tasks. It is a multilingual service that can be configured in 22 languages, including Ukrainian. By combining individual blocks, you can create interactive tasks for students in the form of quizzes, puzzles, racing games, timelines, and interactive images.
7. R.I.D. is a program for learning the Ukrainian language, which introduces the user to three new words every day. For learning these words, the user is awarded a game currency called "sand of time". The more sand a user has, the higher their rating. The program has seven levels. There is also a dictionary that students can use to remember what "thunderstorm", "curtain", and "rain" mean.

Current research (*Krasnenko, 2024*; *Scott, 2024*; *Voshchevska et al., 2023*) clearly shows that gamification has great advantages in the educational process. In particular, it establishes close psycho-emotional interaction between the teacher and the student, activates thinking, attention,

imagination, self-education, and self-organization; it becomes possible to convey educational information in a concise form; students improve their interpersonal communication skills and freely express their opinions. During the pandemic and war in Ukraine, this type of work can be implemented in the process of blended or distance learning.

During practical classes in Ukrainian and English, students at Taras Shevchenko National University of Kyiv were offered to complete final assignments on specific modules in the form of games in Kahoot! and Quizlet. It is worth noting that there is a significant advantage to connecting video links on a selected topic, i.e., students can watch videos on YouTube at the same time. During the practical game classes, teachers used mind maps with QR codes and discussed text material accompanied by media texts and presentations (*Voshchevska et al., 2023, p. 79*). It is worth noting that the Quizlet program is based on the ability to learn vocabulary using flashcards. It extends the concept of learning to a mobile learning environment, which is quite convenient for learners, including additional exercises in writing, spelling, and matching. In other words, the app is well suited for integration into vocabulary development courses.

Collaborative Online International Learning (COIL)

COIL is a powerful innovation in open, intercultural, and multilingual education. It connects classrooms around the world through collaborative online projects (Hackett et al., 2023). In the ESP program for IT, COIL projects allow students to work with foreign colleagues on coding, UX design, or system architecture tasks; use English as a working language in joint presentations or problem-solving sessions; develop soft skills such as intercultural communication and teamwork in a technology-oriented context. The combination of COIL and ESP develops global competencies while strengthening the professional use of English.

For the second year in a row, teachers of the Department of Foreign Languages of the Mathematical Faculties of Taras Shevchenko National University of Kyiv are conducting a COIL project for 1st and 2nd year students majoring in Applied Programming, Software Engineering, "Electronic Communications and Radio Engineering", and "Cybersecurity" in collaboration with the Catholic University of Colombia (Bogotá, Colombia), the University of Santo Tomás (Santiago, Chile), and the American University in the Emirates (Dubai, UAE). Students studied topics according to the educational program (Module "Cybersecurity Essential" and Module "Cyber Risks & Business Intelligence"). While studying the course, students listened to lectures in synchronous mode, and during icebreakers, they communicated in small groups, exchanging information about the customs, peculiarities of education, and youth culture of their countries. In asynchronous mode, teams of students from different countries completed tasks. At the last meeting, each team defended their project. The tasks at this stage develop creativity, critical thinking, and promote authentic language use. Participation in such virtual exchanges simulates real-life situations in the workplace, develops intercultural communication and the ability to work in multicultural teams, and contributes to the creation of a portfolio that demonstrates not only knowledge in a specific field, but also specialized language skills. Participation in COIL modules promotes international academic interaction, the development of critical thinking, and intercultural cooperation through innovative educational formats and work on real projects. Students become leaders, which develops important skills for international partnerships.

Discussion

The integration of innovative technologies into English language teaching for IT professionals offers transformative opportunities, but it also creates significant challenges. Effective implementation requires careful attention to pedagogical alignment, infrastructure, and the human factor. Let us outline the key obstacles that teachers, students, and institutions may encounter, as well as the opportunities that arise from overcoming them.

1. Digital divide and infrastructure gaps—Despite increasing global connectivity, inequality in access to reliable internet, modern devices, and educational software persists, especially in resource-constrained environments. Students and institutions with limited technological infrastructure may find it difficult to take full advantage of innovations such as virtual reality, artificial intelligence, or digital education. This divide risks deepening educational inequality if it is not addressed through inclusive planning and support.
2. Teacher resistance and lack of training—Many teachers, especially those trained in traditional methods, may resist the introduction of new technologies due to lack of knowledge, workload issues, or scepticism about their pedagogical value. Without proper training and ongoing support, teachers may underutilize or misuse tools, leading to superficial integration that does not improve learning.
3. Pedagogical mismatch—A common pitfall is the tendency to use technology for its novelty rather than its educational value. Without a clear pedagogical foundation, tools may be used in ways that do not align with ESP learning outcomes, especially in technical fields such as IT. This can lead to distraction, loss of interest, or overuse of digital platforms.
4. Content licensing and intellectual property issues—although OER promote sharing and adaptation, uncertainty about licensing and attribution can prevent teachers from using or modifying them. Educational institutions may lack clear policies or training on how to legally and ethically implement open content for teaching English to professionals.

Despite the challenges listed above, there are a number of advantages to using technology in ESP teaching for IT students:

1. Personalized and adaptive learning—innovative technologies offer opportunities to adapt ESP teaching to the individual needs of learners. Artificial intelligence-based platforms and learning analytics can provide targeted feedback, identify weaknesses, and recommend resources, thereby supporting differentiated learning. This is especially valuable in teaching English for IT professionals with varying language experience and technical skills.
2. Global collaboration and intercultural skills—virtual exchange projects and COIL modules help students develop not only subject-specific English language skills, but also vital soft skills such as intercultural communication, digital collaboration, and global citizenship. This experience prepares students for the realities of working in multinational IT teams and navigating complex, technology-driven environments.
3. Professional realism and authenticity—technologies such as GitHub, Figma, Jira, and Slack can be incorporated into ESP assignments, providing IT students with authentic platforms for writing, reading, and speaking in a professional context. Practicing English with tools that are actually used in the tech industry makes learning more relevant and realistic.

4. Open pedagogy and collaborative creation—Open Education gives students the chance to be creators, not just consumers of knowledge. Students can collaboratively create glossaries, develop modules for peer learning, or contribute to open ESP repositories. This approach, where each student becomes a creator of materials, promotes engagement, critical thinking, and a deeper connection to the learning process.
5. Scalability and sustainability—digital platforms and open resources allow ESP programs to scale across institutions and borders, offering high-quality learning to a wider audience. Once created, digital content and content based on OER can be reused, adapted, and distributed, promoting long-term sustainability in resource-constrained environments.

While the path to successfully integrating technology into ESP teaching presents real challenges, it also opens up opportunities for improving the quality of education, equity, and engagement. Addressing these challenges through inclusive design, institutional support, and open practices is key to unlocking the full potential of innovation in teaching English for IT professionals.

Conclusions

The integration of innovative technologies into the teaching of ESP for IT students is not only timely but also necessary. As the IT industry continues to evolve and operate rapidly, transcending linguistic and cultural boundaries, language education must also transform to prepare students for real-world communication in a dynamic digital environment.

Research shows that innovative technologies—from artificial intelligence and virtual reality to gamification and collaborative international learning—offer powerful tools for improving the learning of English for specific purposes. When guided by sound pedagogical principles and supported by Open Education, these technologies can help make English for specific purposes more personalized, engaging, and professionally relevant.

At the heart of this transformation is Open Education, which provides the philosophical and practical foundation for scalable, inclusive, and collaborative teaching of English for specific purposes. Through OER, open pedagogy, and global virtual exchanges, teachers can create flexible learning environments that reflect the linguistic and communicative requirements of IT professions while promoting equity and access. By leveraging the power of technology and a philosophy of openness, teachers can transform ESP for IT students into a truly modern, inclusive, and empowering educational experience, preparing graduates for success not only in English but also in the global digital marketplace.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Allen, J. V., & Katz, S. (2020). Teaching with OER during pandemics and beyond. *Journal for Multicultural Education*. https://doi.org/10.1108/JME-04-2020-0027

Bailey, D., & Almusharraf, N. (2021). Investigating the impact of chatbot questions and prompts on student engagement. *2021 1st International Conference on Artificial Intelligence and Data Analysis (CAIDA)*, 85–90.

https://www.researchgate.net/publication/350459684_Investigating_the_Effect_of_Chatbot-to-User_Questions_and_Directives_on_Student_Participation
Bradley, V. M. (2021). Using a learning management system (LMS) with online learning. *International Journal of Technology in Education*, *4*(1), 68–92. https://doi.org/10.46328/ijte.36
Chaw, L. Y., & Tang, C. M. (2018). What makes learning management systems effective for learning? *Journal of Educational Technology Systems*, *47*(2), 152–169. https://doi.org/10.1177/0047239518795828
Coursera. (n.d.). https://www.coursera.org/
Dashtestani, R., & Stojković, N. (2015). The effect of SMS-based L1 and L2 glosses on EAP students' academic vocabulary learning and attitudes. *The Journal of Teaching English for Specific and Academic Purposes*, *3*(3), 521–537. https://doi.org/811.111:159.953.5:621.395
DC4LT Consortium (2019). D*igital Competences for Language Teachers*. https://www.dc4lt.eu/
Freeman, D., Katz, A., Gomez, P. G., & Burns, A. (2015). English-for-teaching: Rethinking teacher proficiency in the classroom. *ELT Journal*, *69*(2), 129–139. https://doi.org/10.1093/elt/ccu074
Hackett, S., Janssen, J., Beach, P., Perreault, M., Beelen, J., & Van Tartwijk, J. (2023). The effectiveness of collaborative online international learning (COIL) on intercultural competence development in higher education. *International Journal of Educational Technology in Higher Education*, *20*, 5. https://doi.org/10.1186/s41239-022-00373-3
Hamzah, W. W., Ismail, I., Yusof, M. K., Saany, S. I. M., & Yacob, A. (2021). Using learning analytics to explore responses from student conversations with chatbot for education. *International Journal of Engineering Pedagogy*, *11*(6), 70–84. https://doi.org/10.3991/ijep.v11i6.23475
Herlina, L., & Said, M. (2022). A need analysis in learning English for law students. *Advances in Social Sciences Research Journal*, *9*(5), 420–428. https://doi.org/10.14738/assrj.95.12438
Kahoot! (n.d.). https://kahoot.com/
Kawachi, P. (2014). *Quality assurance guidelines for open educational resources: TIPS framework* (Version 1.0). Commonwealth Educational Media Centre for Asia (CEMCA). https://www.open-ed.net/oer-quality/validation.pdf
Krajka, J. (2018). Finding quality resources for teachers online. In J. I. Liontas (Ed.), *The TESOL encyclopedia of English language teaching*. Wiley. https://doi.org/10.1002/9781118784235
Krasnenko, O. (2024). Artificial intelligence technologies in ESP. In *Artificial Intelligence in Higher Education: Risks and perspectives of integration: All-Ukrainian scientific and pedagogic internship* (pp. 152–156). Liha-Pres.
LearningApps. (n.d.). https://learningapps.org/login.php
Lu, D. (Jason), & Zeng, Y. (2025). Exploring the use of ChatGPT-generated model texts as a feedback instrument: EFL students' text quality and perceptions. *Innovation in Language Learning and Teaching*, 1–21. https://doi.org/10.1080/17501229.2025.2525341
MinecraftEdu. (n.d.). https://www.minecraft.net/
Observatory Portal: Monitoring the Development of the Information Society towards Knowledge Societies. (2011). *UNESCO*. https://www.unesco.org/webworld/observatory/industry
Opening up education: A support framework for higher education institutions. (2016). *Joint Research Center*. https://joint-research-centre.ec.europa.eu/what-open-education_en
Quizlet. (n.d.). https://quizlet.com/subject/quizlet-5/
Rachmawati, W. I., Kartawinata, B. R., Wijayangka, C., & Hasbi, I. (2020). Factors analysis that affecting the intention to use digital payment (Case study on OVO users in Jakarta, Bogor, Depok, Tangerang, Bekasi). *KnE Social Science*, 290–302. https://doi.org/10.18502/kss.v4i6.6605
Scott, C. L. (2015). *The futures of learning 3: What kind of pedagogies for the 21st century?* UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000243126
Scott, S. (2024). Gamification in English language teaching. *American Journal of Humanities and Social Sciences Research (AJHSSR)*, *8*(7), 298–305. https://www.ajhssr.com/wp-content/uploads/2024/07/ZI24807298305.pdf

Shaping Europe's Digital Future. (2020). European Commission. https://commission.europa.eu/system/files/2020-02/communication-shaping-europes-digital-future-feb2020_en_4.pdf

Silitonga, L. M., Wiyaka, & Prastikawati, E. F. (2024). Boosting students' ESP vocabulary by utilizing AI chatbot. *Eternal: English Teaching Journal*, *15*(2), 275–283. https://doi.org/10.26877/eternal.v15i2.605

Stepanenko, O., Kokhan, O., & Mykhaylova, N. (2023). Opportunities for innovation: Virtual information environment as a means of improving the quality of education. *Innovative Pedagogy*, *60*, 256–260. https://doi.org/10.32782/2663-6085/2023/60.51

Voshchevska, O., Stepanenko, O., & Kuznetsova, L. (2023). Modern concepts of gamification implementation in teaching philological disciplines. *Pedagogy of Formation of Creative Personality in Higher and Secondary Schools*, *89*, 77–81. https://doi.org/10.32782/1992-5786.2023.89.15

Walsh, K. (2015). Emerging Ed Teach: 8 examples of transforming lessons through the SAMR cycle. https://caitlins987307686.wordpress.com/

Wang, Y. F. (2015). Promoting collaborative writing through wikis: A new approach for advancing innovative and active learning in an ESP context. *Computer Assisted Language Learning*, *28*(6), 499–512. https://globelt.org/wp-content/uploads/2025/01/GlobELT-2024-Proceedings-Abstracts-Book-2.pdf

Wang, Y. F., & Petrina, S. (2013). Using learning analytics to understand the design of an intelligent language tutor – Chatbot Lucy. *International Journal of Advanced Computer Science and Applications (IJACSA)*, *4*(11), 124–131. https://doi.org/10.14569/IJACSA.2013.041117

Iryna O. Kryknitska [a][5]

Shaping Brand Identity Through Metaphoric Connotation: The Case of Yves Saint Laurent [4]

Abstract: This article examines the role of creative metaphors coined by Yves Saint Laurent, the brand founder, as mechanisms in constructing the brand identity. Grounded in Conceptual Integration Theory, the study examines how Saint Laurent's metaphorical discourse fuses conceptual domains such as fashion, art, love, freedom, and happiness to produce rich connotations that shape the brand's self-presentation and emotional appeal. The study object is the creative metaphors of the founder of the YSL brand. The study aims to analyze metaphors through the lens of conceptual integration theory as a mechanism for constructing brand identity. The analysis reveals that these metaphors function not only as stylistic semasiological devices that generate emotionally resonant meanings, but are also powerful semiotic tools through which the brand encodes values and communicates its distinct identity. By blending conceptual domains related to clothing and fashion, as well as the core values of the brand and its target consumer identity, the metaphors construct emergent meanings that contribute to connotations that embody the brand identity. Expressions like "a pencil stroke", "a passport for happiness", or "the arms of the man she loves" construct a layered metaphorical narrative in which the brand is positioned as a source of aesthetic refinement, emotional transformation, and existential fulfillment. The connotative network associated with the brand's identity and its underlying mythology encompasses the values of happiness, freedom, confidence, self-realization, love, individuality, as well as conceptual oppositions that resonate with the oxymoronic logic of the brand identity – such as complexity in simplicity and strength in femininity. Crucially, the metaphors articulate identity positions for the consumer, implying that engaging with the brand enables one to access internal states such as confidence, individuality, and romantic completeness. In this way, the brand identity is shaped through symbolic projection: the values encoded in the metaphors — creativity, elegance, sensuality, and freedom — are internalized by the audience as part of their identity narrative. By foregrounding the founder's metaphorical imagination, the study highlights how brand identity emerges not only from visual design or product quality but from the symbolic and emotional universe evoked through language. The metaphors of Yves Saint Laurent construct a coherent and compelling myth for the brand — one that fuses cultural ideals with personal aspirations, thereby ensuring the brand's enduring emotional relevance and symbolic power.

Keywords: creative metaphors, connotations, brand identity, conceptual integration, Yves Saint Laurent.

Abbreviations:

YSL is Yves Saint Laurent.

Introduction

Drawing on Barthes' ideas (*1964*; *1967*), brands sell not just products and services but ideas and values, using connotative meanings intended to replace for the consumer the product or service. The connotations activated by brand advertising focus on associations that the product name and brand name should evoke. These become secondary signifieds, displacing the initial functional value of the product as clothing, food, means of communication, transportation, etc., associating it with success, utility, health, creativity, prestige, and so on. In this context, the

[a] Candidate of Philological Sciences (Ph.D.), Associate Professor, Department of Theory, Practice and Translation of English, Faculty of Linguistics, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.

meanings of signs denoting the brand, products, or services become signifiers connoting values and ideas (signifieds) (*Kravchenko & Yudenko, 2023*).

The discourse of the Yves Saint Laurent (hereafter YSL) brand is significantly represented by metaphorical statements from its founder, quotes that have often been used as brand slogans. The distinctiveness of YSL's metaphors lies not only in their advertising function but also in their role as carriers of cultural myth, creating the perception of the brand as a symbol of freedom, refinement, individuality, and authenticity, shaping the brand's identity.

Despite sustained scholarly interest in metaphor within advertising discourse as an indirect tool of marketing communications (*Phillips, 1997*; *Toncar & Munch, 2001*), its role as a mechanism for creating connotations that underpin brand identity remains insufficiently studied, underscoring the relevance of the chosen topic. The issue of constructing brand identity through metaphors has been partially explored alongside other semasiological stylistic devices (*Kravchenko et al., 2021*; *Kravchenko et al., 2024*). The connotation based on metaphor as a means of creating advertising mythologems has been examined through visual metaphors (*Barthes, 1964*; *Yan & Ming, 2015*; *Williamson, 1978*), albeit without direct relation to brand identity. Similarly, the examination of metaphors in a semiotic aspect, as a means to activate secondary signifieds of brands (*Dyer, 1982*; *Vestergaard & Schrøder, 1985*), overlooks the mechanism of creating such meanings through connotations. In this regard, analyzing the connotative meanings constructed in blends of metaphors as a mechanism for the formation of brand identity defines the novelty and relevance of our study.

The object of study is the creative metaphors of the founder of the YSL brand (*Top 50…, 2025*).

The study aims to analyze metaphors through the lens of conceptual integration theory as a mechanism for constructing brand identity.

Study objectives include

- identifying the creative metaphors used by Yves Saint Laurent in brand-related discourse;
- examining the mental spaces activated in these metaphors and how they interact within blended mental spaces;
- analyzing how metaphorical blends give rise to connotative meanings;
- exploring the role of these meanings in shaping the brand's identity.

A comprehensive study of these aspects will contribute to a deeper understanding of the role of metaphor in the semiotic construction of brand identity as a mechanism for cultural encoding and symbolic value transfer in luxury brand communication. It may be of interest to scholars in cognitive linguistics, branding, advertising discourse, and cultural studies, as well as to practitioners involved in strategic brand communication.

Methods

The study applied a methodology based on Conceptual Integration Theory (*Fauconnier & Turner, 2000*; *Fauconnier & Turner, 2002, pp. 283–304*), suggesting the construction of a conceptual integration network that includes the mental spaces involved in integration: input spaces, a generic space that combines abstract structures common to input spaces, and a blended

space in which projections of elements selected from the input spaces lead to new knowledge structures (*Kryknitska, 2025*).

The conceptual processes underlying cross-dimensional mappings at the Composition and Completion stages of the blend as well as its elaborative potential, are analyzed in terms of the activated connotations that contribute to the construction of brand identity.

Literature Review

Scholarly exploration of metaphor in branding has evolved from classical semiotic analyses (*Barthes, 1964*; *Barthes, 1967*) to cognitive-linguistic and pragmatic perspectives that emphasise meaning construction and consumer interpretation. Barthes (*1964*) viewed advertising discourse as a system of secondary signification in which visual and verbal signs generate cultural myths. Later works such as Williamson (*1978*) and Dyer (*1988*) further demonstrated how advertising transforms ordinary products into symbols of desire and ideology.

The semiotic approach was complemented by cognitive frameworks explaining how metaphor shapes conceptual understanding. Fauconnier and Turner (*2000*; *2002*) introduced Conceptual Integration Theory, according to which metaphor operates through mental spaces and blending processes that create emergent meanings. Their model has been applied in linguistics and marketing to explain how abstract concepts like freedom or happiness become associated with brands through metaphorical projection. Kryknitska (*2025*) adopted this theory to visual metaphors, revealing that conceptual blending provides a mechanism for interpreting complex symbolic imagery in advertising.

Empirical research in advertising discourse supports the persuasive potential of metaphor. Phillips (*1997*) and Toncar and Munch (*2001*) showed that consumers engage more deeply with metaphorical than with literal messages, attributing human qualities to brands and forming stronger emotional connections. Ang and Lim (*2006*) confirmed that metaphorical framing influences perceptions of brand personality and consumer attitudes, particularly in luxury markets. These findings align with the present study's claim that metaphoric connotation constructs identity through emotional resonance rather than through explicit description.

Recent interdisciplinary works expand this understanding by linking metaphor to multimodality and consumer identity. Kravchenko et al. (*2021*) demonstrated that minimalist design and metaphorical language co-create a coherent narrative of sophistication, while Kravchenko and Yudenko (*2023*) analysed multimodal advertising as a cognitive-pragmatic system where visual and verbal signs interact to activate cultural meanings. Similarly, Kravchenko et al. (*2024*) explored the Harley-Davidson myth as a metaphorical construction of freedom, showing how semiotic oppositions structure brand identity—an insight directly relevant to the YSL discourse.

In the context of fashion communication, scholars such as Yan and Ming (*2015*) reinterpreted Barthes' semiology to highlight how fashion signs convey ideological and emotional values. Vestergaard and Schrøder (*1985*) identified advertising language as a rhetorical system that mediates between producer and consumer, while Dyer (*1988*) argued that advertising creates a myth of consumption through the repetition of culturally familiar symbols. These theoretical positions frame YSL's metaphoric discourse as part of a broader semiotic tradition where language not only describes fashion but creates it.

Thus, previous studies converge on several key insights (1) metaphor in advertising functions as a cognitive blend of conceptual domains (*Fauconnier & Turner, 2002*); (2) it operates as a semiotic mechanism producing cultural myths (*Barthes, 1967*; *Williamson, 1978*); (3) it shapes consumer identity through emotional and ideological projection (*Ang & Lim, 2006*; *Kravchenko et al., 2021*).

The present research extends this theoretical continuum by integrating these frameworks to examine how the founder's own metaphors serve as linguistic carriers of YSL's myth. Unlike studies focused on visual or commercial slogans, it analyses the metaphoric discourse of the designer himself as the primary semiotic source of brand identity. Consequently, the study contributes to contemporary branding scholarship by demonstrating that linguistic creativity—rooted in conceptual blending—constitutes a foundational mechanism of cultural encoding within luxury brand communication.

Results

The connotative meanings of "simplicity as complex aesthetics" and "freedom in minimalism" are activated in the blend of the creative metaphor below:

"*The woman in a black dress is a pencil stroke*" (*Top 50…, 2025*).

The metaphor employs iconization—a visual correspondence between the contour drawn by a pencil stroke and the silhouette of a woman in black.

Let us analyze this metaphor through the lens of the Conceptual Integration Theory.

Input Space 1: WOMAN, with prominent elements such as elegance and simplicity.

Input Space 2: PENCIL STROKE, with elements such as minimalism, expressiveness, and the aesthetics of the line.

Generic Space: unites shared elements from the input spaces, including form, visual representation, artistic expressiveness, and the black color.

In terms of conceptual network type, this is a single-scope blend, where the overall structure is drawn from the space of the pencil stroke, while the substantive content comes from the space of the woman. The woman is interpreted in terms of an artistic gesture—rather than the pencil stroke being interpreted in terms of the woman.

Within the blend, various elements from the two input spaces are compressed: The woman in a black dress becomes a graceful monochrome line; The woman is transformed into the embodiment of minimalist beauty; Elegance is abstracted to the point of disembodiment, turning into a line.

In the Completion stage, the structure of the blend is enriched with background knowledge: The woman in black is seen as a work of art, as the embodiment of creative intent (by an artist or designer), and as a symbol of minimalist beauty.

During the Elaboration stage—or mental "running" of the blend—various scenarios and additional meanings (potential implications) may be activated, such as

(a) the black dress as a means of expressing a multifaceted artistic image or idea, associated with the symbolism of black (mystery, potential, power, self-sufficiency);
(b) the ephemerality of beauty—just as a pencil stroke can be erased;

(c) the idea of movement/dynamism: the woman in black as a moment of movement, expression, a fleeting instant of beauty the artist wants to capture (cf. Goethe's Faust: "Stay a while, you are so beautiful!").

Such elements of the blend as "the embodiment of minimalist beauty" and "a work of art" contribute to key codes/secondary signifieds of the YSL brand as elements of its identity: complex simplicity, strength (of expression) in simplicity, and freedom in minimalism.

The metaphor's elaborative potential supports the conceptual architecture of YSL's discourse. The image of the woman as an expressive stroke is associated with such connotations underlying the brand identity, as individuality and freedom, and with restrained extravagance. Simultaneously, the blend resonates with the oxymoronic logic of brand identity, which is built upon oppositions brought into harmony. The metaphor harmonizes key brand oppositions such as

(a) strong—feminine: the stroke is both light and powerfully expressive, just like the image of the woman;
(b) minimalism—semantic depth: the stroke is minimal in form yet rich in meaning (as is the black dress);
(c) restraint—extravagance: the woman in black is not flashy, yet aesthetically striking;
(d) simplicity—complexity: the simple line, like the black dress, carries semiotic and artistic complexity.

Thus, the metaphor "The woman in a black dress is a pencil stroke" encapsulates YSL's brand identity by blending minimalist aesthetics with expressive depth, harmonizing elegance, individuality, and oxymoronic oppositions.

A causal link between the brand (its product), self-confidence, and the feeling of happiness is implied by the metaphor in the statement:

"*When you feel good in a clothing, anything can happen. A good clothing is a passport for happiness"* (*Top 50…, 2025*).

This metaphor blends two input spaces: High-quality clothing (the brand's product) and Passport.

Input Space 1: CLOTHING—includes elements such as:

- an item of appearance;
- a source of comfort and confidence;
- a social status marker;
- a product of the YSL brand;
- a trigger for positive emotions.

Input Space 2: PASSPORT—includes

- a document;
- access/authorization for travel;
- a means of crossing borders;
- a symbol of new opportunities and freedom;
- an attribute of identity (citizenship).

The Generic Space brings together shared elements from both inputs, such as

- an object that grants access to positive experiences;

- a means of transition (to another state or new opportunities);
- a trigger for change and expanded possibilities;
- a tool of identification/self-identification.

From the passport input space, the following elements are projected onto clothing:

Access function: passport → access to countries; clothing → access to an internal state of happiness;

Identity-marking function: a passport indicates citizenship; clothing (especially YSL clothing) indicates style, taste, self-perception, and identity.

In the Blended Space, a new structure emerges: clothing as a means of accessing a state of happiness, fulfilling the needs for confidence and self-realization. The blend creates the connotative meaning of a causal link: Brand (its product) → confidence → happiness.

At the Completion stage, the blend develops the connotative message that the YSL brand product serves as a means of internal transformation, changing not only one's appearance but also one's inner state.

At the Elaboration stage, the blend generates additional connotations that associate the brand's products with the values that form its identity:

- YSL is not just clothing, but a means to achieve inner well-being;
- the YSL brand can make a person happy, functioning as a culturally marked "passport" into a desired emotional state.

The elaboration may further draw on the symbolic potential of the concepts' passport and clothing: the passport symbolizes freedom as new possibilities; clothing symbolizes confidence and self-realization.

Thus, the metaphor blend and its elaborative potential contribute to activating key connotative constants associated with the brand's identity—happiness, freedom, confidence, and self-realization.

The connotative message about YSL's ability to make its target customer happy is reinforced in the blend of an extended metaphor based on the integration of the concepts of clothing, love, beauty, and happiness:

"*The most beautiful clothes that can dress a woman are the arms of the man she loves. But for those who have not had the fortune of finding this happiness, I am there.*" (*Top 50…, 2025*).

Through blending, an image is created in which the brand metonymically becomes the source of what a woman may be lacking—love and happiness. The conceptual integration can be schematically represented as follows:

Input Space 1: CLOTHING, includes elements such as

(a) object of aesthetics;
(b) highlights beauty;
(c) protects and presents the body;
(d) expresses style and individuality;
(e) creates confidence.

Input Space 2: THE EMBRACE OF A LOVED ONE, is structured around

(a) gesture of emotional closeness;
(b) expression of love, warmth, acceptance;

(c) source of comfort and happiness;
(d) iconic gesture of protection.

The Generic Space includes shared elements from both inputs, such as

(a) something that "envelops" a person (literally or metaphorically);
(b) source of emotion;
(c) state of comfort and protection;
(d) means of transitioning to a state of happiness.

In the Blended Space, the following mappings take place: embraces, like beautiful clothing, aesthetically "adorn" the woman; both function as sources of comfort and happiness.

Beauty, love, clothing, and happiness are fused into one emergent space: Love (in the form of an embrace) is the highest form of beauty; Love is happiness; Clothing (when it is by YSL) becomes a substitute for both.

The connotative message "the brand is a substitute for love and happiness" is supported by the subsequent context of the metaphorical expression, which combines two deictic markers—personal and spatial: "I am there." The personal deixis "I" metonymically refers to the YSL brand as an empathetic participant in a woman's life. The spatial deixis "I am *there*" creates an effect of presence, support, and accessibility—the brand is always near, always ready to offer happiness through beauty (i.e., beautiful clothing).

This meaning facilitates the completion of the blend and its further elaboration, activating the secondary connotative signified:

If there is no love → YSL clothing can substitute or simulate this state of happiness.

Thus, the YSL brand appears as a figure of the empathetic Other, ready to give (or compensate for) what is missing. Through the aesthetic experience of wearing YSL clothing, the brand metaphorically restores what a woman may lack—love and happiness.

In this way, the connotative message activated by the metaphor contributes to constructing YSL's identity not merely as a fashion brand, but as a means of attaining emotional intimacy, love, and happiness. Thus, YSL is metonymically positioned as an emotional substitute for love—always present, always ready to give happiness.

Discussion

The analysis of the brand discourse, articulated through metaphorical statements by Yves Saint Laurent himself, demonstrates that the connotative network associated with the brand's identity and its underlying mythology encompasses the values of happiness, freedom, confidence, self-realization, love, individuality, as well as conceptual oppositions such as complexity in simplicity and strength in femininity. These connotative meanings are dynamic elements, activated and elaborated through creative metaphorical blends at the stages of Composition, Completion, and Elaboration. Each metaphor contributes to the semiotic and emotional architecture of the brand by establishing symbolic links between the product and the consumer's inner world—their desires, aspirations, and self-perception.

The metaphors examined in this study implicitly construct a conditional-causal relationship: engaging with the YSL brand—through wearing its clothing and identifying with its aesthetic—leads to the satisfaction of motivational needs such as the longing for love, uniqueness, empowerment, and emotional well-being. In this sense, the brand becomes a catalyst of identity

transformation. To wear YSL is not only to look different but to be different—to embody a version of the self that is more confident, free, more fully realized.

Thus, the metaphors serve as discursive instruments through which the brand's identity is not only articulated but projected onto the consumer, who is invited to merge with its symbolic values, underpinned by metaphorical connotations. The act of choosing YSL becomes an act of self-identification and self-affirmation: If I choose YSL, then I am refined, empowered, desirable, free. In this process, the brand identity and consumer identity become mutually reinforcing. By portraying the brand as a substitute for love, a passport to happiness, or a work of minimalist beauty, the metaphors position YSL as more than a fashion label—it is constructed as an aesthetic and emotional identity framework, offering symbolic belonging and self-expression.

In sum, the connotative meanings generated by the metaphors of Yves Saint Laurent's founder do not merely describe the brand—they construct its identity as a site of personal transformation. Simultaneously, they invite the consumer to partake in this identity, enabling a form of identity co-construction in which the brand and its audience are symbolically and emotionally intertwined.

Discussion

The findings of the study confirm that creative metaphors coined by Yves Saint Laurent perform a key cognitive and semiotic function in shaping brand identity. They not only transmit aesthetic and emotional meanings but also mediate between the brand and its audience, constructing symbolic relationships that transform consumer perception into identity experience. The conceptual integration of domains such as clothing, art, happiness, and love gives rise to connotative meanings that embed the YSL brand within a mythological framework of freedom, sensuality, and individuality.

Through the prism of Conceptual Integration Theory (*Fauconnier & Turner, 2000*; *Fauconnier & Turner, 2002*), each metaphor represents a dynamic mental space in which the notions of beauty, simplicity, and empowerment are blended to form emergent meanings that exceed literal denotation. The metaphor "The woman in a black dress is a pencil stroke" exemplifies how minimalism functions as an expressive code of femininity, while "A good clothing is a passport for happiness" redefines fashion as an emotional gateway to confidence and joy. These metaphors illustrate how linguistic imagination functions as a semiotic tool of branding, equal in importance to visual design or product quality.

The research also demonstrates that YSL's metaphors activate oxymoronic oppositions—strength in femininity, complexity in simplicity, freedom in restraint—that structure the brand's aesthetic philosophy. Such oppositions correspond to the duality of modern identity, simultaneously aspiring to authenticity and transformation. They endow the brand with psychological depth and symbolic richness, allowing consumers to project their inner states and desires onto the brand narrative.

In semiotic terms (*Barthes, 1964*; *Williamson, 1978*), metaphors function as secondary signifiers that produce advertising mythologems. They shift attention from the utilitarian function of clothing to the domain of values and emotions, turning garments into signs of love,

happiness, and self-realisation. Thus, the brand discourse operates as a system of cultural codes that link aesthetic pleasure with existential meaning.

From a cognitive-pragmatic perspective (*Kravchenko & Yudenko, 2023*), the metaphorical blends analysed reveal a process of identity projection, whereby consumers internalise the symbolic values of YSL—creativity, elegance, confidence, sensuality—and integrate them into their self-concept. Engaging with the brand becomes a performative act of self-definition. The metaphors therefore perform a persuasive and affective role, constructing both brand personality and consumer subjectivity.

Consequently, YSL's brand identity emerges as a dialogical construct in which the founder's linguistic creativity generates a myth of emotional completeness. The metaphors serve as cognitive bridges between product and personality, emotion and aesthetics, object and self. They not only describe the brand but embody its philosophy, ensuring that the YSL myth remains culturally resonant and psychologically persuasive in contemporary fashion communication.

Conclusion

This study has examined the role of creative metaphors formulated by Yves Saint Laurent in the construction of YSL's brand identity, applying the tools of Conceptual Integration Theory to reveal the cognitive and connotative mechanisms behind metaphor-driven meaning-making. The analysis has shown that metaphor is a core semiotic strategy through which the brand encodes values, evokes emotions, and communicates its distinct identity.

By blending conceptual domains such as clothing and art, clothing and love, fashion and happiness, or dress and identity, the metaphors construct emergent meanings that contribute to connotations that embody the values of the brand that shapes its identity. The metaphor "The woman in a black dress is a pencil stroke" merges elegance with minimalism, highlighting the aesthetic precision and expressive power of simplicity—a key component of the YSL identity. The metaphor "A good clothing is a passport for happiness" creates a connotative message of emotional access and transformation, implying that YSL is a means of crossing into a state of happiness, freedom, and self-confidence. The metaphor in the statement "The most beautiful clothes are the arms of the man she loves. But for those who have not found this happiness, I am there" positions the brand metonymically as a substitute for love and emotional closeness.

These metaphorical constructions imply a conditional-causal relationship between association with the brand and the satisfaction of motivational needs—love, recognition, self-expression, empowerment, and emotional well-being. In this way, the YSL brand is metaphorically positioned as a transformative force, capable of reshaping not only a woman's outward appearance but also her inner state. This reinforces the brand's mythical function, as it becomes a mediator between desire and fulfillment.

Importantly, these metaphorical blends also play a crucial role in shaping the identity of the consumer. They project the brand's values—individuality, confidence, emotional depth, aesthetic sophistication—onto the target audience, inviting consumers to see themselves reflected in the brand's symbolic framework. The metaphors not only describe what the brand is, but also who the consumer becomes through engagement with it. Thus, metaphors serve as discursive tools of identity construction, both for the brand and its audience. Through these

metaphorical structures, YSL is not only a producer of clothing but also a producer of identity and emotional experience.

The findings of this study contribute to a broader understanding of how metaphor operates in branding discourse—not merely as a rhetorical figure, but as a cognitive and cultural mechanism that shapes brand mythology and identity. They highlight the need to explore further the intersections between metaphor, culture, and consumer psychology, particularly in the domain of high-end branding, where identity formation is a key marketing strategy.

In sum, the metaphors coined by Yves Saint Laurent form a coherent system of connotative messages that establish YSL's brand identity, embodying the emotional, aesthetic, and existential values associated with the motivational needs of the brand's target customer. The brand is constructed not just through its products, but through the metaphors "it lives by", and the identity it offers to those who choose to wear it.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Ang, S. H., & Lim, E. A. C. (2006). The influence of metaphors and product type on brand personality perceptions and attitudes. *Journal of Advertising, 35*(2), 39–53. https://doi.org/10.1080/00913367.2006.10639226

Barthes, R. (1964). Rhétorique de l'image. *Communications*, *4*, 40–51, 1964.

Barthes, R. (1967). *Système de la mode*. Éditions du Seuil.

Dyer, G. (1988). *Advertising as communication*. London: Routledge.

Fauconnier, G., & Turner, M. (2000). Compression and global insight. *Cognitive linguistics, 11*, 3/4, 283–304. http://doi.org/10.1515/cogl.2001.017

Fauconnier, G., & Turner, M. (2002). *The way we think: Conceptual blending and the mind's hidden complexities*. New York: Basic Books.

Kravchenko, N., Valigura, M., Meleshchenko, V., & Chernii, L. (2021). "Simplicity is the ultimate Sophistication" or half a century of IT consumer identity formation: A pragmatics approach. *Token: A Journal of English Linguistics, 13*, 141–169. http://doi.org/10.25951/4824

Kravchenko, N., & Yudenko, O. (2023). Multimodal advertising: semiotic and cognitive pragmatic aspects. *International Journal of Philology*, *14*(4), 6–15. https://doi.org/10.31548/philolog14(4).2023.01

Kravchenko, N., Zhykharieva, O., & Letunovska, I. (2024). Semiotics of Harley-Davidson advertising through stylistics and pragmatics: The concept of freedom in constructing target consumer identity. *Revista Univap*, *30(*65), 1–15. https://doi.org/10.18066/revistaunivap.v30i65.4526

Kryknitska, I. (2025). Cognitive processing of a complex visual metaphor: A conceptual integration theory approach. *Modern Research in Foreign Philology*, *1*(27), 114–123. https://doi.org/10.32782/2617-3921.2025.27.114-123

Phillips, B. J. (1997). Thinking into it: Consumer interpretation of complex advertising images. *Journal of Advertising, 26*(2), 77–87. https://doi.org/10.1080/00913367.1997.10673524

Toncar, M., & Munch, J. (2001). Consumer responses to tropes in print advertising. *Journal of Advertising, 30*(1), 55–65. https://doi.org/10. 1080/00913367.2001.10673631

Top 50 Yves Saint Laurent Quotes (2025 Update). https://quotefancy.com/yves-saint-laurent

Vestergaard, T., & Schroder, K. (1985). *The language of advertising*. Oxford: Basil Blackwell.

Williamson, J. (1978). *Decoding advertisements*. London and Boston, Massachusetts: Marion Boyars.

Yan, S., & Ming, F. (2015). Reinterpreting some key concepts in Barthes' theory. *Journal of Media and Communication Studies, 7*(3), 59–66.

Olha V. Maltseva [a][b]

Digital Educational Tribes: Platform Algorithms and Students' Academic Identity [5]

Abstract: This article analyzes the mechanisms shaping students' academic identity in the digital age, with a focus on educational platforms as emerging spaces of socialization. It explores the phenomenon of *digital educational tribes* — informal student communities formed around algorithmically curated content on learning platforms. The study examines how services such as Coursera, YouTube, and Google Scholar influence the development of academic identity through individualized learning trajectories, self-socialization styles, and content selection. The methodology combines qualitative interviews and digital ethnography. Central to the analysis is the algorithm as a hidden socializing agent that structurally substitutes the educator in the learning process. The theoretical framework draws on Michel Maffesoli's concept of tribal sociality, Danah Boyd and D. Marwick's theories of digital identity, and the platform-based epistemologies of Manuel Castells and Shoshana Zuboff. The findings reveal that students engage not only with educational content but also with norms of communication, cognitive styles, and algorithmically structured logics of interaction. The concept of *digital educational tribes* is introduced as an analytical model of informal online communities where educational participation is structured not around disciplines, but through algorithmic content selection, knowledge aesthetics, and rituals of inclusion. The key notion of *algorithms as educators* allows for a reconceptualization of technological systems as agents of educational influence, replacing traditional academic institutions in the process of structural interaction. Based on qualitative interviews and digital ethnography, the study shows that students' educational behavior is increasingly shaped as a performative identity oriented toward public recognition, aesthetic engagement, and communicative visibility. The article articulates a critical stance on the risks of fragmentation and the loss of worldview coherence in platform-based education. It proposes theoretical approaches for integrating digital educational culture into the academic context without sacrificing cognitive depth, analytical resilience, or systemic pedagogy.

Keywords: digital educational tribes, algorithms as educators, academic identity, platform-based education, epistemic aesthetics, performative participation, educational fragmentation, cognitive resilience, digital ethnography, self-presentation in educational environments, academic subjectivity, epistemological instability.

Abbreviations:

TEDx is an independently organized conference held in the format of TED (Technology, Entertainment, Design).

Introduction

In the contemporary educational landscape, digital platforms are gaining increasing significance, transforming not only access to knowledge but also the very nature of educational participation, subjectivity, and socialization. Platforms such as Coursera, YouTube, and Telegram communities are evolving from mere technical tools into cultural spaces where students construct their academic selves not through institutional curricula, but through content stylistics, algorithmic recommendations, and social rituals of interaction. This phenomenon gives rise to a new analytical category—digital educational tribes: informal online communities

[a] Doctor of Science in Philosophy, Associate Professor, Department of Sociology and Social Work, Pryazovskyi State Technical University. Dnipro, Ukraine.

that coalesce around shared modes of thinking, learning choices, and platform-specific aesthetics of knowledge. Within these communities, academic engagement emerges as a style, a public stance, and a fragment of emotional exchange—rather than as a structured mastery of disciplinary systems.

Algorithms play a pivotal role in this environment as pedagogical agents—technological mechanisms that curate content, suggest educational trajectories, model learning pace, and establish norms of academic interaction. These algorithms effectively perform pedagogical functions without pedagogical accountability: they shape knowledge not according to methodological logic, but based on criteria of popularity, visual appeal, and emotional feedback. Despite evident advantages—flexibility, accessibility, personalization—platforms generate risks of fragmentation, diminished cognitive endurance, and the substitution of learning with stylized participation. Students engage in education through aesthetic impulses, interface convenience, and communicative rituals, distancing the learning process from its foundational nature—methodological, rigorous, critical, and intellectually demanding.

The novelty of this study lies in the introduction and conceptualisation of the phenomenon of digital educational tribes as a new analytical category for understanding the transformation of students' academic identity in platform-based education. While previous research has primarily focused on the digitalisation of learning processes and algorithmic personalisation, this study identifies algorithms as hidden educators—agents that shape students' epistemological behaviour, aesthetic preferences, and cognitive patterns. It proposes a theoretical framework that reinterprets algorithmic curation not merely as a technological feature but as a form of social pedagogy that replaces traditional educational mediation. The research also introduces an interdisciplinary synthesis between Maffesoli's neo-tribalism, digital ethnography, and algorithmic governance, revealing how students' educational participation is increasingly aestheticised and performative, forming identity through visibility and ritualised communication rather than academic mastery.

The subject of the study is the influence of platform algorithms and the socio-aesthetic mechanisms of digital educational tribes on the formation of students' academic identity, motivation, and patterns of educational participation.

The object of the study is the process of academic socialisation of students in the digital educational environment, determined by the structural logic of online platforms.

The study aims to identify the mechanisms through which students' academic identities are formed within digital educational tribes, to analyze the role of algorithmic influence and the social aesthetics of platforms, and to critically reflect on the challenges posed by fragmentation, loss of systemic coherence and intellectual resilience, and the replacement of epistemological depth with symbolic representations of participation and the aestheticization of knowledge.

The research objectives include:

- identifying the typical features of educational participation within digital educational tribes;
- uncovering the functions of algorithms as structures of pedagogical selection and transmitters of social norms;
- analyzing motivational, aesthetic, and ritual factors influencing students' educational choices;

– revealing conflicts between platform flexibility and the demands of academic coherence, disciplinary depth, and professional endurance;
– formulating a pedagogical approach for integrating platform-based education without compromising academic criticality.

Methodologically, the article is grounded in digital ethnography and qualitative interviews, which enable the reconstruction of students' experiences not only as users but also as participants in social ecosystems. The theoretical framework draws upon M. Maffesoli's concept of tribal sociality, Danah Boyd and D. Marwick's theories of digital identity, and approaches to the structural power of algorithms as articulated in the works of M. Castells and S. Zuboff.

The findings may be of value to researchers in digital education, educators, platform designers, and theorists of the social environment of online learning.

Methods

The research employed a combination of general scientific and specialised empirical methods consistent with the interdisciplinary nature of the topic.

At the general scientific level, the study was grounded in a systematic approach that enabled the author to analyse the phenomenon of digital educational tribes as a complex socio-cultural system integrating technological, communicative, and pedagogical components. The dialectical method allowed the identification of contradictions between flexibility and fragmentation, accessibility and loss of academic coherence, as well as between algorithmic automation and human cognitive autonomy. Structural-functional analysis was used to reveal the dual role of algorithms as both technical mediators and socialising agents. Comparative analysis enabled the juxtaposition of traditional academic education with platform-based learning models to identify epistemological shifts in the understanding of knowledge, learning, and academic identity. Hermeneutic interpretation provided the conceptual basis for understanding symbolic meanings, rituals, and aesthetics inherent in platform communication, which function as markers of belonging within digital tribes.

At the specialised level, the research relied on the methods of digital ethnography and semi-structured qualitative interviews with 270 students from Ukrainian and international universities actively engaged in online educational platforms such as Coursera, YouTube, Google Scholar, and Telegram channels. Digital ethnography facilitated the observation of behavioural patterns within platform communities—commenting, liking, sharing certificates, and collective course participation—allowing the identification of tribal markers of social belonging and symbolic interaction. The interview method provided insights into students' motivational structures and perceptions of academic authority in algorithmic environments. Thematic analysis was subsequently applied to classify recurring patterns of meaning, drawing upon engagement theory and social constructivism (*Jensen et al., 2022*; *Toquero, 2021*).

The integration of qualitative methods ensured both the validity and interpretive depth of the findings. This methodological framework enabled the author to reconstruct academic identity formation as a performative and aesthetic process shaped by algorithmic curation, peer interaction, and the aesthetics of digital self-representation. Thus, the study combined philosophical analysis, sociological observation, and empirical verification to capture the multi-layered logic of education in the age of algorithmic mediation

Literature Review

The rapid platformisation of higher education has drawn the attention of numerous scholars who analyse how digital technologies transform pedagogical communication, cognitive behaviour, and the epistemology of learning. Aagaard (*2021*) conceptualises the student as a *customer* within a commodified educational ecosystem, arguing that platform logic redefines the learner's role as a consumer of algorithmically filtered knowledge. Bonilla (*2022*) extends this argument by describing education as a *service economy*, where learning becomes embedded in mechanisms of attention and engagement rather than cognitive depth.

Maffesoli's (*1996*) theory of *neo-tribalism* provides the sociological foundation for understanding the phenomenon of *digital educational tribes*. He argues that late-modern society is structured around emotionally cohesive micro-communities united by shared aesthetics and rituals. Hardy, Bennett, and Robards (*2018*) adapt this concept to the digital sphere, emphasising the fluidity and performativity of online communities. Vorobjovas-Pinta (*2021*) further deepens this perspective, showing that tribal belonging in digital contexts is maintained through symbolic boundaries and collective rituals—principles directly relevant to educational platforms.

The epistemological aspect of algorithms as agents of socialisation has been explored by Introna (*2016*), who describes the *governmentality of algorithms* as a new mode of academic regulation. Kitchin (*2017*) complements this view by revealing how recommendation systems construct cognitive enclaves and "echo chambers," while Williamson and Eynon (*2024*) identify the *hidden curriculum* of algorithmic personalisation that shapes learning pathways subconsciously. Gallagher, Breines, and Blaney (*2020*) highlight that algorithmic pedagogies redefine the balance between automation and student agency in post-pandemic education.

From the psychological and motivational perspective, Bourdieu's (*1984*; *1986*) theory of *symbolic capital* and Ryan and Deci's (*2000*) *self-determination theory* explain why visibility, recognition, and performative participation become key motivators in digital learning environments. Students accrue symbolic capital through certificates, likes, and public self-presentation (*Lawler, 2011*; *Lebaron, 2013*), turning educational achievement into a social performance.

Selwyn (*2019*) and König and Wenzel (*2023*) warn that such aestheticisation of education may erode methodological consistency, substituting analytical rigour with engagement metrics. Their findings align with Bonilla's (*2022*) notion of *educational commodification*, where platforms prioritise interactivity over depth.

In methodological terms, digital ethnography (*Jensen et al., 2022*; *Toquero, 2021*) emerges as an effective approach to studying these transformations, as it captures authentic practices of engagement, symbolic exchange, and algorithmic mediation within online communities. Rush Dreker and Downey (*2023*) also stress the significance of cultivating a *digital academic identity* as part of career development, reinforcing the necessity to understand identity as both performative and relational.

Thus, the reviewed literature demonstrates that modern education is being restructured by algorithmic, aesthetic, and social logics. Existing studies address individual elements—algorithmic bias, motivation, or social belonging—but lack a unified model integrating these

components. The present research bridges this gap by conceptualising digital educational tribes as a complex synthesis of algorithmic pedagogy, symbolic sociality, and aesthetic communication. It thereby extends current theoretical discourse by redefining educational identity as an algorithmically mediated and performatively enacted construct, situated within the broader transformation of digital culture (*Papacharissi, 2010*; *Marwick, 2013*).

Results

Algorithms as hidden agents of socialization

In the digital educational environment, recommendation algorithms—e.g., on platforms such as Coursera, YouTube, and Google Scholar—perform not only the technical function of content selection but also a socializing role that often remains unnoticed. They shape educational trajectories, influence academic interests, and even affect students' perceptions of themselves as subjects of knowledge.

This effect can be compared to the concept of hidden pedagogy or hidden curriculum—that is, the implicit transmission of norms, values, and expectations through the structure of the educational environment rather than through formal content. In the case of algorithms, this is manifested in the fact that they:

- amplify popular topics, reducing the visibility of niche or critical directions;
- create echo chambers of academic content, where the student sees only what already corresponds to their previous actions;
- shape the idea of "quality knowledge" through view metrics rather than academic depth.

As noted in the study *The Hidden Curriculum of Algorithms: How Personalization Shapes Learning Pathways* (*Williamson & Eynon, 2024*), algorithms can narrow cognitive horizons, reinforce biases, and reduce diversity of thought in the learning process. This creates a hidden pedagogy in which the student learns not only content but also norms of behavior, styles of thinking, and algorithmic logic.

In this context, the algorithm emerges as a "hidden educator"—an agent without a face, yet possessing structural power over what the student sees and learns. As Gallagher, Breines, and Blaney (*2020*) point out, automation in education changes the very nature of pedagogy, creating new forms of interaction between the student and the digital environment.

Thus, educational platform algorithms should be considered not only as technical tools but also as hidden agents of socialization that shape academic behavior, identity, and perceptions of knowledge. Their influence is implicit but systemic—and requires critical reflection within pedagogical theory and practice.

Digital Educational Tribes: Concept and Features

The concept of the "digital educational tribe" is an adaptation of the notion of neo-tribalism proposed by French sociologist Michel Maffesoli. In his work *Le temps des tribus* (1988), translated into English as *The Time of the Tribes: The Decline of Individualism in Mass Society* (*Maffesoli, 1996*), he describes modern society as fragmented into small, emotionally cohesive groups—"tribes" that unite around lifestyles, symbols, rituals, and shared experience. These communities

do not have rigid structures but possess a "state of mind" that defines their internal logic, aesthetics, and behavioral norms.

In the digital educational context, such tribes form around platforms—Coursera, YouTube, Telegram, Google Scholar, and others—where students not only consume content but also interact, identify, and integrate into communities with their own rules, language, and authorities. These tribes exhibit the following features:

- *normativity:* internal rules that regulate communication style, content evaluation, and topic acceptability;
- *language and symbols*: use of terms, memes, and visual codes that mark affiliation;
- *participation rituals*: regular commenting, liking, and participation in joint courses or challenges;
- *inclusion and exclusion*: mechanisms for accepting new members or marginalizing "outsiders";
- *flexible identity*: a student may belong to several tribes simultaneously, adapting their participation style depending on context.

As noted by Hardy, Bennett, and Robards (*2018*), digital tribes are not stable structures but rather temporary zones of sociality that arise around shared interest or emotional experience. In the case of educational platforms, this may involve a course, topic, instructor, or even the style of material delivery.

A critical analysis of neo-tribalism is also provided by Vorobjovas-Pinta (*2021*), who, through an ethnographic lens, shows how space, ritual, and symbolic boundaries shape temporary communities. This allows educational platforms to be viewed as environments of social inclusion, where academic identity is formed not only through content but also through participation in tribal culture.

Thus, the concept of the digital educational tribe enables the description of informal student communities that emerge within platform-based education. They possess their own social logic, which does not always align with academic structure but significantly influences students' identity, motivation, and educational behavior.

Mechanisms of Student Academic Identity Formation

Academic identity is a set of knowledge or skills and the awareness of oneself as a subject within the academic environment, capable of critical thinking, research, and participation in scholarly discourse. In the digital age, this process is increasingly mediated by algorithms that determine what a student sees, what interests them, and how they position themselves (*Rush Dreker & Downey, 2023*).

On educational platforms, recommendation algorithms (e.g., Coursera, YouTube, Google Scholar) create personalized learning trajectories that do not always align with the academic logic of sequence. Through interaction with content, the student gradually forms an understanding of what is considered "academic", which topics are important, which authors are authoritative, and even which thinking style is acceptable.

This process involves several defining mechanisms:

- *algorithmic selection*: the student sees only those courses, videos, or articles that correspond to their previous actions—creating an "academic echo chamber" effect (*Kitchin, 2017*);

- *fragmentation of knowledge*: instead of a systematic course, the student receives a mosaic of topics, which may complicate the formation of a coherent academic position (*Selwyn, 2019*);
- *platform aesthetics of knowledge*: the style of material presentation (visual, emotional, brief) influences how the student perceives academicity—e.g., a TEDx video may seem more "scientific" than a textual article;
- *interactive socialization*: comments, likes, subscriptions—these are not just behaviors but forms of academic participation that shape a sense of belonging to a community.

As D. Marwick (*2013*) notes, academic identity in the digital environment is performative—the student is not merely learning but acts as a platform participant, demonstrating their engagement, thinking style, and position. This creates a new form of academic subjectivity, formed not in the classroom but in an algorithmically structured environment.

Thus, student academic identity in the digital age is shaped through interaction with algorithms, platform aesthetics, and social mechanisms of participation. It is a complex process in which the student becomes not only a consumer of knowledge but also a participant in a digital academic culture with its norms, rituals, and logic.

Research Data: Interviews and Digital Ethnography

To identify how students form academic identity within digital educational tribes, qualitative research methods were applied—specifically semi-structured interviews and digital ethnography. These methods allowed for the description of behavioral practices and the interpretation of students' reflective motivations related to educational participation.

Methodology:

- Interviews were conducted with 270 students from Ukrainian and international universities who actively use Coursera, YouTube, Google Scholar, and Telegram channels for self-directed learning;
- The sample included students aged 19–25 from various disciplines (social sciences, humanities, IT, ecology); the most active contributors in educational platform chats were invited to participate;
- Digital ethnography was performed through participant observation in the mentioned educational chats, open course comments, and Discord communities;
- Thematic analysis was applied, based on engagement theory and social constructivism (*Jensen et al., 2022*; *Toquero, 2021*).

Key Observations

Identity through the Platform. The formation of students' academic identity in the digital age increasingly occurs not through institutional context (university, faculty, studied disciplines), but through platform affiliation. This trend reflects a shift in the structure of educational subjectivity, where identity is built on the basis of interaction with the platform, its symbols (certificates, logos, course ratings), and social mechanisms (visibility in the community, comments, likes).

Academic identity in this context performs a performative function: the subject is not merely learning but demonstrates belonging to the educational environment through public

rituals (*Marwick, 2013*). Coursera, YouTube, Telegram communities, etc., appear not only as content delivery channels but as spaces of social self-expression, where learning is simultaneously an act, a style, and a symbol.

The concept of "digital self-branding" (*Papacharissi, 2010*) helps to understand how the platform becomes a medium for projecting oneself as an academic subject. Identity is no longer tied to disciplinary logic but to the logic of the environment in which the action takes place. This leads to fragmentation but also enhances agency—the student independently chooses their academic trajectory, supported by visual and social representation.

Among the responses to the question about the components of academic identity, the vast majority indicate a significant shift toward platform-based education.

Below are typical responses to this question:

"It doesn't matter where I study—what matters is that I have a Coursera certificate. It looks solid. I even include it in my resume, though it was a short course" (female student, 24, Lviv).

"I don't consider myself a university student, although I am one. I've been studying through YouTube and Google Scholar for three years. It's my choice" (male student, 22, Kyiv).

"I don't know who taught this course—what matters is that it had good ratings and was trending on YouTube" (female student, 20, Bratislava).

Thus, students form their educational identity not through formal institutions but through platform affiliation.

Algorithmic Trust. The shift in the source of educational authority is a key feature of modern platform-based education. Whereas knowledge was previously acquired through figures such as teachers, scholars, and institutions, today more and more students rely on the algorithm as a structural intermediary that indicates what is worth studying, how it should be presented, and what is considered high-quality.

This phenomenon is described within the framework of the concept of "algorithmic authority" (*Introna, 2016*; *Kitchin, 2017*), which asserts that algorithms—despite lacking subjectivity—generate institutionalized trust, mediated by interface design, popularity, likes, and cultural legitimization. Students perceive recommended content as inherently relevant—which complicates the development of critical thinking and source analysis skills.

A risk of cultural automatism emerges, where educational choices are based on platform logic rather than reflection. This creates a new behavioral norm: if something is shown—it must be worth studying. Academic trust is delegated to technological systems that lack transparency regarding selection mechanisms. This is directly reflected in interview results:

"If a video is in the recommendations—I assume it's worth attention. I don't Google further—it's already verified." (Student, 20, Krakow)

"I'm subscribed to a Telegram channel that shares top courses. The algorithm clearly knows I'm interested in psychology—I get new materials daily." (Student, 21, Ivano-Frankivsk)

Thus, students develop trust in the algorithm as an authority that replaces academic selection and critical inquiry.

Educational Aesthetics and Rituals. In the digital education environment, the aesthetic component of materials (visual style, design, emotional delivery) becomes not just a supplement but a central criterion of educational value for many students. This shift reflects a trend toward

the platform-based aestheticization of knowledge—where educational products are evaluated not so much by content as by their mode of representation.

This can be explained through the theory of platform-based knowledge consumption (*Bonilla, 2022*), which describes learning as a cultural practice involving the choice of style, participation rituals, and social symbols. Joint course participation, certificate exchange, and video discussions are formats of interaction that structurally resemble tribal behavior, as described in the concept of "neo-tribes" (*Maffesoli, 1996*).

In interviews, students using these educational resources emphasize the appeal of the aesthetic component, as it aligns with the contemporary information-cultural environment, unlike traditional academic teaching.

"I only take courses that have a beautiful visual cover. If the design is boring—I don't open it. That's important." (Student, 23, Odesa)

"In our group, we agree on which courses to take together. We ask those who've completed them about their impressions and choose the most stylish and vivid ones. Then we exchange certificates. It's already a tradition." (Student, 25, Prague)

"When you earn certificates on Coursera, you feel like you belong to a separate world where everyone strives to move forward." (Student, 22, Edmonton)

We can conclude that aesthetics act as a marker of belonging, and rituals serve as social cement for the educational community. This approach creates a new cultural logic—academicity emerges not through methodological depth but through style, form, and collective participation. Student knowledge consumption relies on aesthetics, shared rituals, and symbols of success, resembling tribal sociality.

Motivation: Visibility and Recognition. Motivation for learning in the digital educational environment is increasingly shaped not by interest in content, but by visibility within the community and public recognition. Educational achievements become part of performative capital they are displayed, published, and evaluated.

This phenomenon is closely linked to Pierre Bourdieu's theory of "symbolic capital" (*Bourdieu, 1984*; *Bourdieu, 1986*), which asserts that social practices of status exchange (in our case—certificates, comments, participation) structure the internal hierarchy of the community. In the digital educational tribe, prestige is earned not only through knowledge but also through activity, publicity, and aesthetic representation of oneself as a participant. Symbolic capital is increasingly in demand in the social environment (*Lebaron, 2013*; *Lawler, 2011*). Below are several testimonies gathered during digital ethnographic expeditions:

"I publish all my certificates on LinkedIn. Even those that lack substance. It's about image, not knowledge." (Student, 22, Ternopil)

"This will be my 15th certificate. It's a real treasure, currency. It's like the time spent learning has been materialized and now has a tangible form." (Student, 23, Berkeley)

This supports the concept of reflexive motivation (*Ryan & Deci, 2000*), where the need for recognition becomes the driving force of action. Learning transforms into a formation of public exposure of the academic self, where content often yields to style and participation rituals.

Concern with image-related aspects, representational assets for the job market, rather than deep professional preparation, is evident in comments left by course participants on digital

educational platforms. They also openly express enthusiasm about their belonging to local educational communities.

"I like being part of the community. When I leave a comment—I feel like I'm in the loop. That's more important than just completing the course." (Student, 19, Frankfurt am Main)

These statements point to a sense of tribal belonging, emotional engagement, and collective motivation. Clearly, student motivation is often shaped not by knowledge itself, but by recognition and visibility within educational sociality (*Sheldon & Gunz, 2009*).

This is also confirmed by results of digital ethnography, obtained through methods such as virtual participation and real-time observation on educational platforms, where course participants eagerly share their online learning experiences.

Among the behavioral patterns identified:

- *Participation rituals*: weekly course completion, certificate publication in profiles, lecture discussions in Telegram groups, etc.;
- *Formation of local norms: commenting style* ("speak with arguments," "don't post if you haven't taken the course"), mutual support, material recommendations;
- *Linguistic self-identification*: "I'm a viewer of technical content," "I follow a philosophy channel"—this indicates educational identity as a choice of disciplinary space.

All of this confirms the thesis that students' academic identity today is increasingly constructed not through institutional canon, but through dynamic participation in digital educational tribes.

Thus, reflexive typical examples from interviews and digital ethnography demonstrate that students are not merely learning—they are integrating into an environment where knowledge, thinking style, and social interaction share a common logic defined by algorithms and platform culture.

Platform Logic vs Academic Sequence

Digital educational platforms, especially those relying on personalization algorithms, often operate according to the logic of quick accessibility, entertainment, and fragmented content consumption. This contradicts the traditional principles of academic education, which presuppose methodological consistency, depth of topic exploration, and reflective thinking.

Recommendation algorithms tend to amplify what already "works" in the digital environment: popular courses, short videos, emotional headlines, and interactive formats (*König & Wenzel, 2023*). As a result, students receive an educational experience that resembles cultural consumption more than academic learning.

This paradigm shift has several consequences:

- *Fragmentation of knowledge*: material is not presented linearly but broken into short fragments—complicating the formation of holistic understanding (*Aagaard, 2021*).
- *Loss of epistemological logic*: students often do not realize how topics are interconnected or what underpins the knowledge being taught.
- *Commercialization of learning*: educational content is often designed for engagement rather than pedagogical value, altering the motivational nature of learning (*Bonilla, 2022*).

- *Informational isolation*: students receive content that confirms their interests rather than challenges them intellectually—leading to echo chambers and reduced academic diversity (*Selwyn, 2019*).

One interview respondent noted:

"I like courses where the videos are five minutes long, and you can just skip the unnecessary stuff. I don't need to dive deep—the main thing is that the algorithm gives me something quick." (Student, 21, Kharkiv)

This indicates that platform logic has reshaped perceptions of educational quality, where speed and comfort outweigh depth, structure, and cognitive tension.

Thus, while digital platforms foster tribal sociality, they simultaneously contribute to the de-academization of educational content, creating risks of knowledge fragmentation, superficial thinking, and lowered standards of pedagogical consistency. This challenge requires new forms of theoretical reflection and adaptation of educational strategies to digital logic.

Discussion

The educational environment emerging in the digital age is no longer a neutral backdrop for learning. It becomes an aesthetic and social space where students construct academic identity not only through knowledge but through symbols, rituals, and styles of interaction. Digital educational tribes' communities of like-minded individuals on platforms—provide a sense of belonging, horizontal exchange, and flexible navigation of educational content.

However, this flexibility has a dual nature. On one hand, it opens possibilities for independent thinking, adaptation, and autonomous trajectory formation. On the other—it generates risks of fragmentation, lack of pedagogical and worldview coherence, and the substitution of systematic thinking with stylized participation, where knowledge is not a deep experience but a public gesture. Instead of academic tension—convenience; instead of discussion—comment; instead of structure—intuitive aesthetics.

Educational performativity, based on certificates, reputation, and visibility, may hinder the development of cognitive endurance—the ability to work on complex tasks that lack quick results, visual appeal, or instant recognition. And it is precisely this endurance—working with texts, concepts, data, and unconventional challenges—that underpins professional maturity.

This is also a problem of professional unfitness: real conditions for applying knowledge—production cycles, corporate demands, interdisciplinary conflicts—are not tailored to mood or balanced by aesthetic preferences. There is no room for romanticized learning in a pleasant interface with a programmed loyalty system—instead, there is routine complexity, obligation, and intellectual challenge. What matters there is not a chat comment but a debate with an opponent; not a like but an argument; not inspiration but structure.

Thus, we face the need to reconsider the role of digital educational tribes: are they a useful supplement to systemic education—or a flawed substitute that undermines academic logic itself? The pursuit of comfort, platform coziness, and tension-free learning is not the strategy that prepares one for the challenges of the real world. It may be a stage of entry into knowledge, but not a paradigm for acquiring it.

This problem is not only pedagogical but also cultural-ontological. Education as thinking, not as style; as labor, not as participation; as immersion, not as a like. This is where the fine line lies—between flexibility and chaos, between self-expression and academic discipline.

Conclusion

The study demonstrated that digital educational platforms do not merely change the way knowledge is accessed—they shape a new logic of educational socialization, where the student is seen not as a bearer of disciplinary systematics but as a participant in a ritual of cognition occurring within aesthetic, algorithmic, and social resonance.

The formation of academic identity in the digital age takes place within platform culture, which offers quick accessibility, comfortable navigation, and visible participation—instead of structured methodology, cognitive tension, and worldview coherence. Education becomes aestheticized and communicative, and simultaneously vulnerable to fragmentation, as the student shifts from a stable academic position to a stylized educational presence.

This situation highlights a critical threshold that cannot be ignored. Digital convenience is not a substitute for intellectual endurance. Educational tribes are horizontal communities, but they do not provide the verticality of development—sequential thinking, argumentation, methodological depth. The pursuit of optimized conditions for knowledge may limit the student's ability to overcome complexity, which is the foundation of professional maturity.

Knowledge acquired within academia is applied not in spaces where the user chooses the genre or interface, but in situations where intellectual discipline is subordinated to production or professional dynamics. There, visual appeal does not prevail—clarity of decision does; not inspiration, but sustained argumentation. This is where the epistemological inadequacy of the platform as a sole educational strategy becomes evident.

The digital educational ecosystem produces not only new tools and formats but also a new typology of academic participation, emerging in the form of digital educational tribes—informal communities united not around discipline but around platform, aesthetics, and interaction style. In these communities, the student plays the role not merely of a knowledge recipient but of a performer of the educational "self," acting publicly, fragmentarily, and within algorithmic resonance.

Digital educational tribes—as community, logic, and technology—may complement academic education, but they do not replace it. Their value lies in mobility, accessibility, and inclusivity—but not in depth, methodology, or cognitive tension. Education as thinking, as labor, as position formation—cannot be built solely on the basis of the platform.

This is where the second key concept arises—algorithms as pedagogues. They are not neutral aggregators—they perform pedagogical selection, shape educational trajectories, set the rhythm of participation, and define quality through popularity. This is a technical structure that effectively replaces the teacher's function, but without a guaranteed methodological framework, without epistemological responsibility.

This platform–tribe–algorithm triad, while valuable in forming an accessible, intuitive, aesthetic educational model, cannot be the sole paradigm. It does not ensure cognitive endurance, does not cultivate academic reflection skills, and does not teach how to live and think in a world where knowledge is not tailored to convenience.

Fragmentation resulting from platform logic is not merely a technological feature—it becomes an epistemological trap in which the student loses the connection between knowledge and its application. And the algorithm, though convenient, does not teach how to overcome complexity—it merely offers what is most popular. Therefore, platform-based education does not reproduce academic knowledge—it reconstructs it according to the logic of sociality, aesthetics, and algorithmic selection.

Hence, it is necessary to develop a deep scientific-pedagogical theory of integration that will define approaches such as:

- the role digital educational tribes can play in the educational continuum;
- how to ensure the connection between aesthetic participation and methodological systematics;
- how to form an educational culture where flexibility is not an excuse for fragmentation.

Creating a new critical theory of knowledge and a new pedagogy for the digital age will allow us to find adequate correlations between academic teaching and platform-based education.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Aagaard, J. (2021). The platformization of education: The student as a customer. *Learning, Media and Technology, 46*(3), 252–263. https://doi.org/10.1080/17439884.2021.1897002

Bonilla, C. A. (2022). Commodification in educational platforms: Learning as a service. *Critical Studies in Education, 63*(4), 481–499. https://doi.org/10.1080/17508487.2020.1796017

Bourdieu, P. (1984). *Distinction: A social critique of the judgment of taste*. London: Routledge & Kegan Paul.

Bourdieu, P. (1986). The forms of capital. In J. Richardson (Ed.), *Handbook of Theory and Research for the Sociology of Education* (pp. 241–258). New York: Greenwood.

Gallagher, M., Breines, M. R., & Blaney, D. (2020). Digital learning in post-pandemic higher education: Algorithmic pedagogies and student agency. *Teaching in Higher Education, 25*(4), 501–517. https://doi.org/10.1080/13562517.2020.1773308

Hardy, A., Bennett, A., & Robards, B. (Eds.). (2018). *Neo-Tribes: Consumption, Leisure and Tourism*. Cham: Springer. https://doi.org/10.1007/978-3-319-68207-5

Introna, L. D. (2016). Algorithms, governance, and governmentality: On governing academic writing. *Science, Technology, & Human Values, 41*(1), 17–49. https://doi.org/10.1177/0162243915587360

Jensen, L. X., Bearman, M., Boud, D., & Konradsen, F. (2022). Digital ethnography in higher education teaching and learning—a methodological review. *Higher Education, 84*, 1143–1162. https://doi.org/10.1007/s10734-022-00838-4

Kitchin, R. (2017). Thinking critically about and researching algorithms. *Information, Communication & Society, 20*(1), 14–29. https://doi.org/10.1080/1369118X.2016.1154087

König, R., & Wenzel, F. (2023). Digitalization of higher education: Understanding the role of recommendation systems. *European Journal of Education, 58*(1), 123–141. https://doi.org/10.1111/ejed.12527

Lawler, S. (2011). Symbolic capital and the construction of social identity. In M. Wetherell & C. T. Mohanty (Eds.), *The SAGE Handbook of Identities* (pp. 131–146). London: SAGE.

Lebaron, F. (2013). Symbolic capital. In A. Michalos (Ed.), *Encyclopedia of quality of life and well-being research* (pp. 6537–6543). Dordrecht: Springer. https://doi.org/10.1007/978-94-007-0753-5_2961

Maffesoli, M. (1996). *The time of the tribes: The decline of individualism in mass society* (D. Smith, Trans.). London: SAGE.

Marwick, D. (2013). *Status update: Celebrity, publicity, and branding in the social media age*. Yale University Press.

Papacharissi, Z. (2010). *A networked self: Identity, community, and culture on social network sites*. New York: Routledge. https://doi.org/10.4324/9780203876527

Rush Dreker, M., & Downey, K. J. (2023). *Building Your Academic Research Digital Identity: A Step-Wise Guide to Cultivating Your Academic Research Career Online*. Springer. https://doi.org/10.1007/978-3-031-50317-7

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Selwyn, N. (2019). *Should robots replace teachers? AI and the future of education* (1st ed.). Polity Press. https://www.wiley.com/en-gb/Should+Robots+Replace+Teachers%3F%3A+AI+and+the+Future+of+Education-p-9781509528967

Sheldon, K. M., & Gunz, A. (2009). Psychological needs as basic motives, not just experiential requirements. *Journal of Personality, 77*(5), 1467–1492. https://doi.org/10.1111/j.1467-6494.2009.00589.x

Toquero, C. M. D. (2021). Digital ethnography on students' authentic engagement in social media platforms during the global online experiment. *Journal of Digital Educational Technology, 1*(1), ep2104. https://doi.org/10.21601/jdet/11310

Vorobjovas-Pinta, O. (2021). Neo-tribalism through an ethnographic lens: A critical theory approach. In A. Pabel, J. Pryce, & A. Anderson (Eds.), *Research paradigm considerations for emerging scholars* (pp. 112–129). Bristol: Channel View Publications. https://doi.org/10.21832/9781845418281-011

Williamson, B., & Eynon, R. (2024). The Hidden Curriculum of Algorithms: How Personalization Shapes Learning Pathways. *Learning, Media and Technology, 49*(1), 22–41. https://doi.org/10.1080/17439884.2023.1964567

Khrystyna I. Serednytska [a][Z]

Study of Thermal Rectification in a Bi-Material with Interfacial Inhomogeneities [d]

Abstract: Thermal rectification is a phenomenon of heat exchange that allows heat to be transferred in one direction to a lesser extent than in the other. The study of this process enables the control of temperature, energy conversion, and the creation of potentially new materials. Studies of the thermal rectification effect using nanofiber compounds are known in the literature, in which the heat flow causes different heat transfer in both directions by changing the operating temperature, and thus, in one direction, the connected structure plays the role of a dielectric, in the other — a conductor. In this article, the phenomenon of thermal rectification is studied based on a model of thermos-elastic behaviour of a bi-material with interfacial inhomogeneities. It is assumed that the interfacial inhomogeneities are filled with some substance and are characterised by a given thermal conductivity coefficient. It is demonstrated that inhomogeneities along the interfacial line of the bi-material result in varying heat transfer depending on the direction of the heat flow and the properties of the bi-material components. The phenomenon of thermal rectification for such a model consists in increasing the difference between the values of effective thermal resistance for two opposite directions of heat flow. It has been established that the lower the thermal conductivity of the inhomogeneities and the greater the density of their location, the more pronounced the phenomenon of thermal rectification becomes.

Keywords: bi-material, interfacial inhomogeneities, thermal conductivity, thermal rectification.

Introduction

Developing novel materials with predictable properties such as thermal conductivity, electrical conductivity, and mechanical compliance is crucial for modern technologies. These properties can be imparted through various methods, including combining different materials, creating geometric and physical surface inhomogeneities, doping, and applying influencing factors like electric and magnetic fields. A key application of such material engineering is in thermal management. For instance, experimental studies on a thin film of vanadium dioxide deposited on a silicon wafer have demonstrated a radiative thermal rectifier (*Ito, K. et al., 2014*). In this system, the operating temperatures are precisely adjusted by doping the film with tungsten.

Thermal rectification is a phenomenon that is often used to regulate the electrical conductivity of a material by changing the temperature. For example, mass-loaded carbon and boron nitride nanotubes exhibit asymmetric axial thermal conductance, with greater heat flow occurring in the direction of decreasing mass density (*Wang et al., 2014*). Similarly, the thermal rectification coefficient is enhanced by increasing the geometric asymmetry in nanostructures such as graphene (*Wang et al., 2017*). To investigate these principles, experimental studies on defect-engineered graphene have utilized focused ion beam methods to create defects with precisely controlled sizes and locations (*Nobakht et al., 2018*). In some materials, this temperature-dependent phenomenon is also coupled with changes in electrical conductivity, offering a potential route for its regulation.

Thermal rectification occurs in bi-material structures in the presence of surface roughness

[a] Candidate of Physical and Mathematical Sciences (Ph.D.), Head of the Laboratory, Pidstryhach Institute for Applied Problems of Mechanics and Mathematics, National Academy of Sciences of Ukraine. Lviv, Ukraine.

at the material contact points, a thermal potential barrier between the material contacts, and a difference in the temperature dependence of thermal conductivity between different materials at the contact point (*Roberts et al., 2011; Chumak et al., 2012*). Nanoscale bi-material thermal rectification induced by a bi-material interface has been experimentally verified and its underlying mechanism investigated using molecular dynamics simulations (*Ye et al., 2017*). The thermal diode consists of polyamide (PA) and silicon (Si) nanowires in contact with each other. It has been found that temperature has a negligible effect on the rectification coefficient, while decreasing the contact length or increasing the temperature difference can enhance the rectification coefficient. These results are related to the development of solid-state thermal diodes based on the interface. The thermal rectification effect of a solid is demonstrated in the article (*Shrestha et al., 2020*), using the heterogeneous transition of "irradiated-pure" polyethylene from nanofibers using electron irradiation. For irradiated nanofiber samples, it is shown that the heat flux can be rectified by changing the operating temperature, and the average thermal rectification coefficient is significantly higher than the experimental values obtained in previous studies.

However, achieving a large and controllable rectification effect remains a significant challenge, as it requires either a macroscale or a substantial temperature shift, and experimental methods are typically quite expensive. This article proposes a theoretical approach to study the phenomenon of thermal rectification based on a bi-material endowed with interfacial inhomogeneities, which cause the appearance of thermal resistance under the action of a heat flow.

Materials and Methods

Consider the bi-material, which consists of two isotropic materials D_1 and D_2 with different thermomechanical properties. A periodical system crack is located at the bi-material interface (*Figure 1*). The height of the crack is given by $h_0(x)$, the length is $2a$, period of the location of the cracks is d. At infinity, the bi-material is subjected to uniformly distributed tensile and shear forces p, S_1, S_2, respectively, and a stationary homogeneous heat flow q. Under the action of the load the cracks are opening the resulting height of the gaps will be $h(x)$,. The cracks are filled with a substance that penetrates the crack from the external environment or material by diffusion or filtration. We assume that the crack filler does not resist deformation of the body and is characterised by a thermal conductivity coefficient λ_c. When heat and force are transferred across a bi-material interface, imperfect thermal contact occurs between faces of the cracks. Outside the cracks, mechanical and thermal contact is ideal.

The heat transfer between the faces of the cracks is modelled by the thermal resistance and the longitudinal thermal conductivity of the filler (*Martynyak & Serednytska, 2017*). The thermal resistance is directly proportional to the thermal conductivity coefficient of the filler and inversely proportional to the height of the gap formed during the loading process. The longitudinal thermal conductivity is equal to the product of the thermal conductivity coefficient of the filler and the height of the crack. We assume that the heat flow between the faces of the cracks in the transverse direction is continuous.

The thermal and mechanical boundary conditions on the crack are as follows:

$x \in (-a+kd, a+kd)$:

$\tau_{xy}^{+}(x) = \tau_{xy}^{-}(x) = 0,\ \sigma_y^{+}(x) = \sigma_y^{-}(x) = 0$

$\lambda_c h(x) \frac{\sigma^2}{\sigma x^2}\left(T^{-}(x) - T^{+}(x)\right) + 12 q_y{}^{+}(x) - 12\frac{\lambda_c}{h(x)}\left(T^{-}(x) - T^{+}(x)\right) = 0,\ q_y^{-}(x) = q_y^{+}(x)$ (1)

where the superscript "+" and "–" denote the boundary values of temperature T, normal components of heat flow q_y, normal and tangential stress components τ_{xy} and σ_y on the x-axis in the upper and lower half-plane, respectively.

Using the method of complex potentials (*Chumak et al., 2012*) and contact boundary conditions (1), the formulated problem is reduced to a nonlinear system of singular integrao-differential equations with a Hilbert kernel with respect to functions that have the physical meaning of the temperature jump $\gamma(x)$ between the crack surfaces and the height $h(x)$ of the formed gaps:

$\frac{1}{d}\int_{-a}^{a} h(t)\, ctg\left(\frac{\pi(t-x)}{d}\right) dt + \frac{\lambda\eta}{2}\left(\gamma(x) - \gamma_{ef}\right) = -\frac{G^*}{2}p + \frac{1}{d}\int_{-a}^{a} h_0'(t)\, ctg\left(\frac{\pi(t-x)}{d}\right) dt,\ h(a) = 0,$

$|x| < a,$

$\lambda_c h\gamma''(x) + \frac{6\lambda}{\pi}\int_{-a}^{a} \gamma'(t)\, ctg\left(\frac{\pi(t-x)}{d}\right) dt - \frac{12\lambda_c}{h(x)}\gamma(x) = -12q,\ \gamma(a) = 0, |x| < a,$ (2)

where

$\gamma_{ef} = \frac{1}{d}\int_{-a}^{a} \gamma(x)\, dx,\ G^* = \frac{(1-k_1 k)}{G_1(1-k_2)},\ G_1(1-k_2) = G_2(1-k_1),\ k = 3 - 4\upsilon_n,$

$\lambda = \frac{2\lambda_1\lambda_2}{(\lambda_1+\lambda_2)},\ \lambda_2 = \lambda_1,\ \eta = \eta_2 - \eta_1,\ \eta_n = \frac{\alpha_n(1+\upsilon_n)}{\lambda},\ n = 1,2;\ \upsilon_1, \upsilon_2$ are Poisson's ratios,

G_1, G_2 are shear moduli,

α_1, α_2 are coefficients of linear thermal expansion,

λ_1, λ_2 are thermal conductivities of materials D_1 and D_2.

The resulting system (2) was solved using a modified analytical-numerical procedure (*Serednytska et al. 2019*) based on the methods of collocations and successive approximations.

Effective temperature jump γ_{ef} is determined by the solution of the system (2). The value of the temperature jump γ_{ef} characterises the additional temperature distribution caused by the periodic system of cracks. The effective temperature jump is a function of the heat flow $\gamma_{ef}(q)$.

Effective thermal resistance is a parameter that characterises the interfacial contact thermal resistance of a bi-material and is defined as differentiation of effective temperature jump function with respect heat flow $R_{ef}(q) = \frac{\delta\lambda(q)}{\delta q}$.

The effective temperature jump γ_{ef} and the effective thermal resistance R_{ef} depend on the density and direction of the heat flow.

The phenomenon of thermal rectification consists of increasing the difference between the values of effective thermal resistance for two opposite directions of heat flow.

The direction of the heat flow is determined by the parameter η, which is the difference in thermal distortivity of materials. The coefficient of thermal distortivity of a material $\eta_n (n = 1, 2)$ characterises the curvature of a rectilinear element due to a heat flow q of unit intensity perpendicular to this element. The coefficient of thermal distortivity is determined by the thermomechanical properties of the material. It is believed that if the difference in thermal distortions is positive $\eta > 0$, then the heat flow is directed to the material with a greater thermal distortivity. If the difference in thermal distortivity is negative $\eta < 0$, then the heat flow is

directed to the material with a lower thermal distortivity.

The thermal rectification parameter δ determines the relative error between two values of effective thermal resistance R_{ef}^{+} and R_{ef}^{-} for two cases of heat flow direction towards the material with greater thermal distortivity and towards the material with less thermal distortivity, respectively $\delta = \left|\frac{R_{ef}^{+} - R_{ef}^{-}}{R_{ef}^{+}}\right| \times 100\%$.

Thus, to assess the phenomenon of thermal rectification, it is sufficient to analyse the change in the parameter δ. The larger the parameter δ, the greater the thermal rectification of the bi-material.

Literature Review

The phenomenon of thermal rectification has become a subject of growing interest due to its potential applications in thermal management, energy conversion, and the creation of materials with direction-dependent heat transfer. The fundamental principle of thermal rectification—where heat is transmitted more efficiently in one direction than the other—was first observed in solid-state systems and later extended to nanoscale structures and bi-material interfaces (*Roberts & Walker, 2011*). These early studies established the basis for understanding asymmetric heat transfer arising from differences in interfacial thermal resistance and the temperature dependence of material properties.

Further development of the concept was achieved through the study of thermoelastic interactions in bi-material systems. Chumak and Martynyak (*2012*) demonstrated that thermal rectification could occur between two thermoelastic solids due to the presence of rough zones at the interface. Their model revealed that the degree of rectification is influenced by the periodicity and amplitude of surface irregularities, which act as heat barriers. This theoretical foundation led to a growing number of studies exploring how geometric asymmetry and interface imperfections can affect the efficiency of heat transfer in bi-material structures.

Experimental confirmation of the effect was obtained through studies of nanostructured materials, where the manipulation of lattice configurations and defect distributions allows for precise control over thermal conductivity. For instance, Wang et al. (*2014*) reported that phonon confinement in asymmetric nanostructures can induce a substantial rectification effect even in single-material systems, thus proving that geometric asymmetry alone can serve as a driving factor. Similarly, Wang et al. (*2017*) performed experiments on suspended monolayer graphene and demonstrated that heat flux asymmetry can be tuned by altering the structural geometry and defect density. These results confirmed that thermal rectification could be achieved through nanoscale engineering of structural asymmetry.

In the domain of graphene-based materials, Nobakht et al. (*2018*) revealed that introducing asymmetric structural defects significantly alters phonon transport, resulting in enhanced rectification. Their research underlined the importance of defect engineering for modulating thermal flow in two-dimensional materials. Such studies paved the way for understanding how localized interfacial inhomogeneities—including cracks, voids, or fillers—can modify effective thermal resistance and facilitate rectifying behaviour in composite systems.

At the same time, Ito et al. (*2014*) introduced a novel radiative thermal rectifier using a vanadium dioxide (VO_2) thin film on a silicon substrate. The film's radiative properties were

tuned by tungsten doping, enabling controlled transition between conducting and insulating states depending on temperature. This experiment demonstrated that radiative heat transfer could also exhibit rectifying behaviour, expanding the concept beyond solid conduction mechanisms.

Theoretical studies of bi-material interfaces further advanced understanding of how heat transfer can be influenced by the thermomechanical properties of component materials. Martynyak and Serednytska (*2017*) developed an analytical framework for contact problems of thermoelasticity in bi-materials with interface cracks, demonstrating that the presence of filled or partially filled cracks introduces additional temperature jumps that modify the local heat flux. Their findings emphasised that the interaction between mechanical stress, temperature gradients, and interface morphology governs the resulting effective thermal resistance.

Later research by Ye and Cao (*2017*) provided molecular dynamics simulations of bi-material nanocontacts, proving that nanoscale interfaces between materials with dissimilar thermal conductivities can yield measurable rectification effects. Their results indicated that decreasing contact length or increasing the temperature gradient enhances the rectification coefficient. This confirmed that both contact geometry and temperature-dependent conductivity are key determinants in achieving controllable rectification.

More recently, Shrestha et al. (*2020*) examined solid-state dual-mode rectifiers based on heterogeneous polyethylene nanofibres, showing that electron irradiation can induce transitions between irradiated and pure states that strongly affect the heat flux directionality. Their experiments produced significantly higher rectification coefficients than those reported in previous studies, highlighting the role of material irradiation and phase transition as tools for thermal control.

Finally, Serednytska, Martynyak, and Chumak (*2019*) extended these findings by analysing the thermoelastic state of a bi-material with an open gas-filled interface crack. Their analytical–numerical approach provided insights into how interfacial inhomogeneities contribute to heat transfer asymmetry. Building upon these theoretical models, current research focuses on bi-materials with periodic interfacial inhomogeneities, where the density, thermal conductivity, and deformation properties of the filler substance determine the degree of rectification. The cumulative evidence from these studies demonstrates that the interplay of structural geometry, material properties, and external stress enables precise tuning of heat transport characteristics in advanced functional materials.

Results

The main results of the thermal rectification study are illustrated in the appendix (*Figure 2*; *Figure 3*; *Figure 4*; *Figure 5*; *Figure 6*). Based on the solution of system (2), the value of the effective thermal resistance for the considered bi-material was determined. The difference between the values of the thermal resistance for the two directions of the heat flow was analysed.

Numerical calculations were performed for a bi-material characterized by the following dimensionless quantities:

$$\bar{x} = \frac{x}{d},\ \bar{a} = \frac{a}{d},\ \overline{h_0} = \frac{h_0}{d},\ \bar{q} = qd\eta,\ \bar{p} = pG^*,\ \bar{\lambda}_c = \frac{\lambda_c}{\lambda},\ \bar{\gamma}_{ef} = \gamma_{ef}\lambda\eta,\ \bar{R}_{ef} = \frac{R_{ef}d}{\lambda},\ \bar{k}_t = 2\bar{a},$$

$$\bar{\delta} = \left|\frac{R_{ef}^{+} - R_{ef}^{-}}{R_{ef}^{+}}\right| \times 100\%,\ \bar{h}_0(\bar{x}) = 0.001(1 - \bar{x}^2)^{3/2}.$$

The change in the effective thermal resistance of the bi-material $\bar{R}_{ef}$ depending on the direction and density of the heat flow $\bar{q}$ for different fixed values of the forces $\bar{p}$, the coefficient of thermal conductivity $\bar{\lambda}_c$ and the coefficient of interface heterogeneity $\bar{k}_t$. Note that the coefficient of interface heterogeneity $\bar{k}_t$ determines the density of the cracks' location. The larger the value of the coefficient $\bar{k}_t$, the more densely the cracks are located, the smaller the value $\bar{k}_t$, the further the cracks are from each other. The direction of the heat flow depends on the value $\bar{q}$: if $\bar{q} > 0$, then the heat flow is directed to the material with greater thermal distortivity, if $\bar{q} < 0$, then the heat flux is directed to the material with less thermal distortivity. The dependence of the thermal rectification parameter on the heat flow is determined by the relative error between the values of the dimensionless effective thermal resistance for the two directions of the heat flow. Figure 2 shows the dependence of the effective thermal resistance $\bar{R}_{ef}$ on the heat flow $\bar{q}$ for different values of the thermal conductivity $\bar{\lambda}_c$ (*Figure 2*). It can be seen that with increasing heat flow density, thermal resistance increases in the case of a flow directed to a material with greater thermal distortivity and decreases in the case of a flow directed to a material with less thermal distortivity. An increase in the thermal conductivity $\bar{\lambda}_c$ leads to a decrease in thermal resistance $\bar{R}_{ef}$. The effect of tensile forces on the change in effective thermal resistance $\bar{R}_{ef}$ is proportional to the intensity of the forces $\bar{p}$ (*Figure 3*). Thermal resistance $\bar{R}_{ef}$ increases with increasing the forces $\bar{p}$ for both directions of the heat flow. With increasing $\bar{k}_t$, the effective thermal resistance $\bar{R}_{ef}$ increases and the difference between the values of the thermal resistance for two opposite directions of the heat flow increases (*Figure 4*). The effective thermal resistance acquires greater values in the case of a flow directed to a material with greater thermal distortivity.

A nonlinear dependence of the thermal rectification parameter $\bar{\delta}$ on the heat flow density $|\bar{q}|$ was found (*Figure 5*) for different values of the thermal conductivity of the crack filler $\bar{\lambda}_c$. An increase in the heat flux density leads to an increase in the thermal rectification parameter. With an increase in thermal conductivity $\bar{\lambda}_c$, the value of the parameter $\bar{\delta}$ decreases, which means a decrease in thermal rectification. The thermal rectification parameter simultaneously increases with an increase in the density of the gaps and a decrease in the intensity of tensile forces (*Figure 6*). The dependence of thermal rectification on the density of the cracks' location, which indicates a different thermal distortivity of the bi-material depending on the number of cracks located along a unit length of the interface.

Therefore, an increase in the values of the effective thermal resistance and the thermal rectification parameter of the bi-material manifests itself with an increase in the heat flow density and a decrease in the resistance to heat transfer through the interface. Accordingly, the ability of the interface to transmit heat is characterised by the presence of inhomogeneities such as cracks, their density of location, and the thermal conductivity of the substance that fills them.

Discussion

The phenomenon of thermal rectification demonstrates how, by altering the temperature, it is possible to control the electrical conductivity of materials. Alternatively, by adjusting the dimensions and geometry of the material structure, it is also possible to achieve the desired heat

transfer. This effect can be used in engineering developments to create new devices or materials that can convert thermal energy into valuable electrical energy. Experimental studies on various types of nanostructured materials enable us to gradually increase the thermal distortion parameter, confirming the effect itself and refining existing methods for converting thermal motion into directed current. Theoretical approaches to studying the phenomenon of thermal rectification can facilitate the development of a mathematical model for a device based on a material with controllable properties, such as thermal conductivity and electrical conductivity. Therefore, theoretical studies of thermal rectification for bi-materials can logically be continued for electrically conductive interface inhomogeneities and piezoelectric bi-materials.

Conclusion

The phenomenon of thermal rectification is studied based on a model of a bi-material consisting of components characterised by different thermomechanical properties, and at the interface of which there is a periodic system of heat-conducting inhomogeneities, such as cracks. Interface inhomogeneities introduce an additional temperature difference, resulting in a change in thermal resistance during heat transfer through the interface, which depends on the direction of the heat flow. The problem of thermoelasticity for a bi-material with interfacial cracks is reduced to a system of nonlinear singular integro-differential equations concerning the functions of crack opening and the temperature jump between their surfaces. Using analytical-numerical methods for solving such systems, the additional temperature distribution as a function of the heat flow, as well as the effective interfacial thermal resistance, are determined. The thermal rectification parameter is analysed based on the values of the effective thermal resistance determined for two opposite directions of the heat flow. It is shown that changing the direction of the heat flow leads to qualitatively different values of thermal resistance, and the difference between these values increases with increasing heat flow and significantly depends on the thermal conductivity of the crack filler and the parameter characterising the density of the crack location, as well as on the influence of the force load. The thermal rectification parameter determines the relative error in percentage between the values of the effective thermal resistance for two opposite directions of the heat flow and increases with increasing flow. Thus, the phenomenon of thermal rectification in a bi-material with different coefficients of thermal distortivity of its components is manifested to a greater extent at high values of the heat flow density, low thermal conductivity of the interface and low intensity of tensile forces. The results obtained show a qualitative change in the thermal rectification parameter and can be used as a model for engineering calculations.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Chumak, K. A., & Martynyak, R. M. (2012). Thermal rectification between two thermoelastic solids with aperiodic array of rough zones at the interface. *International Journal of Heat and Mass Transfer*, *55*, 5603–5608.

Ito, K., Nishikawa, K., Iizuka, H., & Toshiyoshi, H. (2014). Experimental investigation of radiative thermal rectifier using vanadium dioxide. *Applied Physics Letters*, *105*, 253503. https://doi.org/10.1063/1.4905132

Martynyak, R. M., & Serednytska, K. I. (2017). Contact Problems of Thermoelasticity for Interface Cracks in Bimaterials. Lviv: Publishing House "Rastr-7".

Nobakht, A. Y., Gandomi, Y. A., Wang, J., Bowman, M., Marable, D. H., Garrison, B., Kim, D., & Shin, S. (2018). Thermal rectification via asymmetric structural defects in graphene. *Carbon, 132*, 565–572. https://doi.org/10.1016/j.carbon.2018.02.087

Roberts, N. A., & Walker, D. G. (2011). A review of thermal rectification observations and models in solidmaterials. *International Journal of Thermal Sciences, 50*, 5. 648-662. https://doi.org/10.1016/j.ijthermalsci.2010.12.004

Serednytska, K., Martynyak, R., & Chumak, K. (2019) The thermoelastic state of a bi-material with an open gas-filled interface crack. *Journal of Theoretical and Applied Mechanics, 57*, *2*, 331–341. https://doi.org/10.15632/jtam-pl/104587

Shrestha, R., Luan, Y., Luo, X., Shin, S., Zhang, T., Smith, P., Wei Gong, Bockstaller, M., Tengfei Luo, Chen, R., Hippalgaonkar, K., & Sheng Shen. (2020). Dual-mode solid-state thermal rectification. *Nature Communications*, *11*, 4346. https://doi.org/10.1038/s41467-020-18212-2

Wang, H., Hu, S., Takahashi, K., Zhang, X., Takamatsu, H., & Chen, J. (2017). Experimental study of thermal rectification in suspended monolayer graphene. *Nature Communications*, 8, 15843. https://www.nature.com/articles/ncomms15843

Wang, Y., Hu, J., Qiu, B., Chen, Y., & Ruan, X. (2014). Phonon lateral confinement enables thermal rectification in asymmetric single-material nanostructures. *Nano Letters, 14*, 592–596. https://pubs.acs.org/doi/abs/10.1021/nl403773f

Ye, Z. Q., & Cao, B. Y. (2017). Thermal rectification at the bi-material nanocontact interface. *Nanoscale*, *9*, 11480–11487.

Appendix

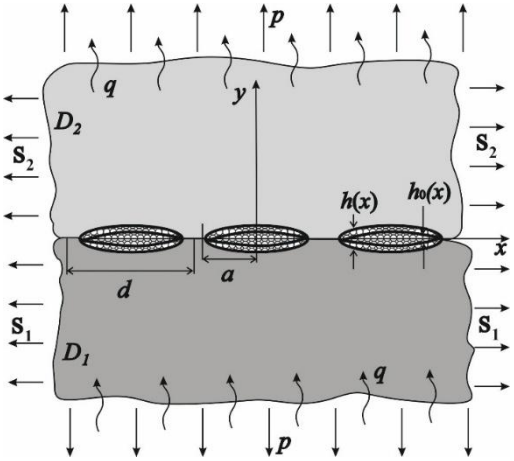

Figure 1. Shema of bi-material

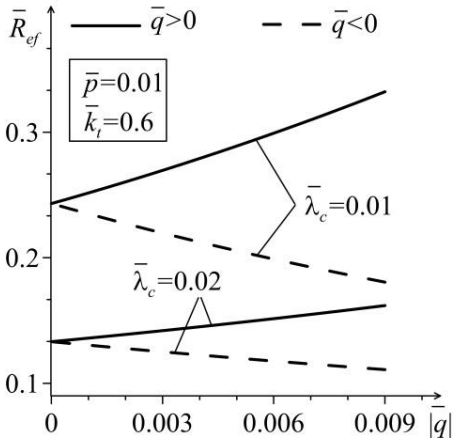

Figure 2. Dependencies of the thermal resistance $\bar{R}_{ef}$ on the heat flow $\bar{q}$ for different values of the thermal conductivity $\bar{\lambda}_c$.

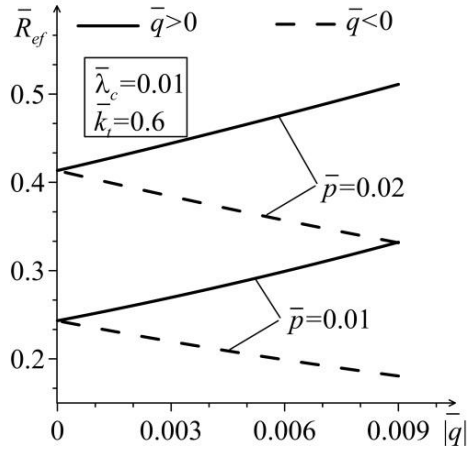

Figure 3. Dependencies of the thermal resistance $\bar{R}_{ef}$ on the heat flow $\bar{q}$ for different values of the intensity of forces $\bar{p}$.

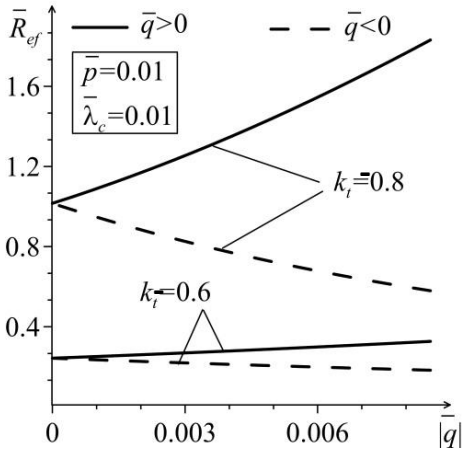

Figure 4. Dependencies of the thermal resistance $\bar{R}_{ef}$ on the heat flow $\bar{q}$ for different values of parameter $\bar{k}_t$.

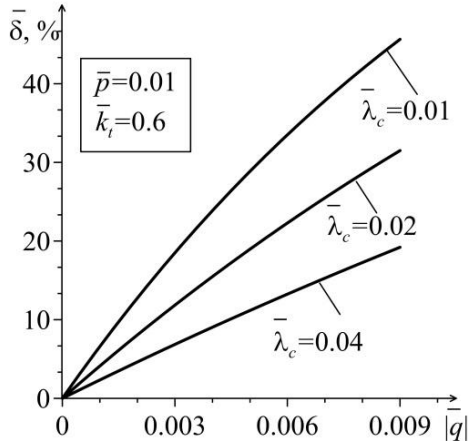

Figure 5. Dependencies of parameter of thermal rectification $\bar{\delta}$ on the heat flow density $|\bar{q}|$ for different values of the thermal conductivity $\bar{\lambda}_c$.

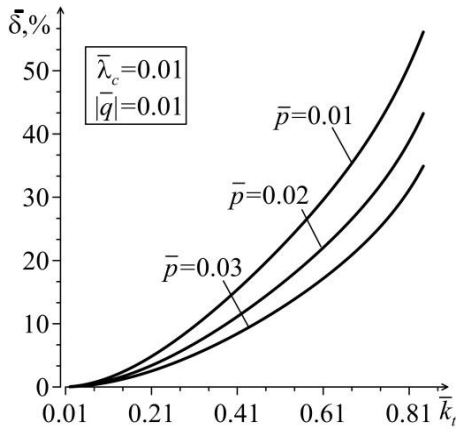

Figure 6. Dependencies of parameter of thermal rectification $\bar{\delta}$ on the coefficient of interface heterogeneity $\bar{k}_t$ for different values of the intensity of forces $\bar{p}$.

Liana V. Spytska [a][&]

Peculiarities of Manifestation of Paranoid Delusions in the World [Z]

Abstract: The relevance of the investigated problem lies in several debatable issues that the psychiatric community is trying to solve, one of which is the definition of clear clinical criteria for paranoid delusions. Long-term studies of disorders of thinking, perception, will, motor activity, which cause the formation of false conclusions about the surrounding world, today do not provide a comprehensive answer to the causes of the distorted consciousness of an individual. The purpose of the study is the diagnosis and research of the limits of the manifestation of paranoid delusions, which develops in the context of a personality disorder. The main method used to study the features of the manifestation of paranoid delusions was the clinical-psychopathic method. To conduct it, psychometric methods, psycho-diagnostic methods, as well as clinical and statistical methods of data processing were used as an auxiliary research tool. During this empirical study of the patient's personality, his intelligence, and cognitive abilities, it was possible to achieve results according to which the main criteria of a personality with manifestations of paranoid delusions were determined. Therefore, the main results of the study are the determination of the general regularity of the combination of mental and behavioural disorders, as a result of which a change in the clinical picture of the disease is observed. The general level of perception of the quality of life of patients with paranoid delusions was determined; a reasonably high level of suicidal risk; the reasons for the low level of social interaction in the professional and family spheres are revealed; identified determinants that increase depressive symptoms; the main behavioural strategies used by patients to interact with the surrounding people in the environment are presented. The practical significance of the materials of the article lies in the further successful correction of borderline states of mental illnesses in psychotherapy; in organizational psychiatric treatment; prevention and rehabilitation of mental pathologies.

Keywords: pathological condition, delusion, psychiatry, mental disorder, schizophrenia.

Abbreviations:

AAS is American Association of Suicidology,

DD is depressive disorders,

$PANSS$ is Positive and Negative Syndrome Scale,

PPD is paranoid personality disorder,

$WHOQOL-SM$ is World Health Organization Quality of Life, special module.

Introduction

At the beginning of the 20th century, when psychiatry went beyond the boundaries of psychiatric hospitals, the modern stage of studying the borderline states of mental illnesses and psychotherapeutic forms of assistance to broad segments of the population began. According to the International Classification of Diseases 11th revision (ICD–11) (*2022*), paranoid delusion syndrome is a symptom of three mental disorders: schizophrenia of the paranoid type, delusional disorder, and PPD. The following scientists studied the peculiarities of the manifestation of paranoid delusions—Kh. Zhyvaho (*2021*), S. Fedorchuk et al. (*2020*), O. Napreyenko (*2019*), M. Craske et al. (*2019*), M. Zimmerman (*2021*), J. Casarella (*2020*). O.

[a] Four-Time World Science Champion and Three-Time Olympic World Champion in Science, Doctor of Psychology, Ph.D. in Law, Full Professor, Department of Psychology and Pedagogy, Kyiv International University. Kyiv, Ukraine.

Syropyatov et al. (*2021*)—the main cause of the pathogenesis of paranoid delusions is considered to be a malfunction of the central nervous system. According to them, the process of transmitting excitation and inhibition impulses is disrupted due to the underdevelopment of neurotransmitters. Brain cells are in an ultra-paradoxical phase. In such a phase, the image formed in the imagination does not correspond to reality.

Delusions and hallucinations are productive psychopathological symptoms that can be eliminated in therapy. However, A. Borozenets et al. (*2020*) prove that signs of paranoid delusions are very difficult to correct or cannot be corrected at all. A peculiar idea about the environment, contrary to the inconsistency with the surrounding reality, acquires the character of a special world-view. Attempts by people close to them to rationalize the falsity of their beliefs lead to isolation, limiting the patient's contacts, which can lead to a complex form of schizophrenia. S. Stavytska et al. (*2021*) call paranoid delusions autistic fantasizing—when it is difficult for patients to explain the nature of their inner experiences. This is due to the fact that the fundamental characteristic of this syndrome is thought disorders. S. Stavytska et al. describe in their works the results of a study in which patients with symptoms of paranoid delusions demonstrate disordered work of abstract thinking, disturbances in the work of logical thinking and rational cognition, which provoke a pathological interpretation of surrounding events. Objects and phenomena of the environment are displayed, their internal connections are distorted and perceived in this way. From the patient's point of view, such conclusions are always logically justified. Paranoid delusion is not systematic in nature, it is inconsistent, fragmentary, fantastic, often accompanied by emotional disorders, fear, confusion, anxiety. When delusional ideas acquire a more coherent system, paranoid occurs, and the inclusion of nonsensical, delusional ideas indicates the development of paraphrenia. Both signs are characteristics of severe forms of schizophrenia.

Paranoid schizophrenia is one of the most common diseases in which paranoid delusions develop. The etymology of schizophrenia, distinguishing only paranoid delusions, is characterized by stable delusional ideas of one month or more. During this period, delusions of persecution or its varieties are formed, and at the moment when the patient's legend finds its confirmation in the environment (purely based on his beliefs), "crystallization of delusions" occurs, a certain delusional system is built, which develops into the next stage. At this stage, delusions of grandeur appear. The inner world of such a person is impoverished, and to experience such a disconnection with one's own self, the psyche forms hallucinations in the form of a fantastic world and the special purpose of the individual in it. However, to establish a diagnosis of "schizophrenia", it is required to determine the presence of a complete list of clinical symptoms according to the ICD–11 (*International Classification…, 2022*). Determining paranoid personality disorder as a separate psychiatric diagnosis is a primary task of psychiatry, because the indicators of some symptoms cannot be attributed to schizophrenia or any other type of psychopathy. There are transitional states that have been clinically confirmed in a group of schizoids with narcissistic and dissocial types of disorders, on the basis of which the basis of paranoid development and delusions emerges (*Deisenhammer et al., 2019*). The difficulty of establishing a diagnosis of paranoid personality disorder lies in the lack of a clear distinction between delusional ideas of other aetiology.

Therefore, the difficulties in identifying delusional symptoms form the relevance of the purpose of the study to identify the diagnostic minimum for the study of anomalies of personality disorders of people with paranoid delusions, which will serve to specify the diagnosis and speed up high-quality outpatient and therapeutic treatment.

Materials and Methods

During the research, the following theoretical research methods were applied: analysis, synthesis, concretization, generalization of scientific and methodological literature on psychology, psychiatry, philosophy. Among the diagnostic methods, the following psychometric methods were used: the PANSS (*Napreyenko, 2019*), the suicidal risk scale of the AAS (*Syropyatov et al., 2021*), a special module for patients with endogenous psychoses WHOQOL-SM (*Zhyvaho, 2021*); psychodiagnostic methods: method of diagnosing the level of social frustration of L.I. Wasserman in the modification of V.V. Boyko, individual-typological questionnaire L.N. Sobchyk (*Stavytska et al., 2021*); psychological observation and psychiatric interview. With the help of clinical and statistical methods, data processing was performed using the methods of descriptive statistics and graphical representation of the results.

An experimental psychological study of mentally ill patients was conducted using the clinical-psychopathological method in accordance with the tasks set in the article. So, the experiment was started with the formation of a sample, which was 421 schizophrenic patients aged 20 to 46 years. In most patients, the disease lasts from two years, a special requirement was the absence of diseases of the central nervous system, chronic diseases of the body. After collecting and studying the anamnesis of the patients, an experimental group was selected, which included 160 patients. Upon completion of the organizational measures, the diagnostic part of the experiment was immediately started. This stage took a long time. There was a lot of diagnostic material, and due to significant cognitive loads, patients quickly got tired. Therefore, it was very important to establish a trusting relationship with the patients, thus laying the groundwork for interaction with them in the research process. For this, a psychiatric interview was conducted with the respondents before starting the diagnosis. Through frank conversation, they tried to win the patient's trust in themselves, showing a desire to understand the patient through interest, sympathy, and empathy.

Analysing the anamnesis of the respondents during the psychiatric interview and carefully collected information from the control card of dispensary care for a patient with a mental disorder, it was found that the diagnosis of schizophrenia is combined with other mental disorders. Namely, DD (36 patients), chemical addictions and non-chemical addictions (35 and 33 patients, respectively), anxiety-phobic and obsessive-compulsive disorders (OCD) (32 patients), as well as personality disorders (24). Diagnosis using psychometric and psychological methods continued throughout the year. During this time, 30 indicators of schizophrenia symptoms were studied with a gradation from 1 to 7 (where 1 is the absence of a symptom, 7 is its severity). PANSS (*Napreyenko, 2019*) has 3 subscales in total.

The suicidal risk scale of the American Association of Suicidology (*Syropyatov et al., 2021*) has 4 modules in which, according to a 5-point system (where 1 is the minimum level of symptom expression), the following were determined: the level of suicidal thoughts and their intensity, signs of suicidal behaviour, and the level of danger of suicidal attempts. Subjective

assessment of the quality of life of mentally ill patients covers such areas of life as "positive/negative emotions and the ability to manage them", "cognitive functions", "ability to perform routine tasks", "ability to work", "personal relationships", the sphere of social interaction (rest, entertainment, relationships with loved ones and relatives), "orientation in oneself and the surrounding reality", "self-control". The maximum number of points according to the WHOQOL-SM (*Zhyvaho, 2021*) method can be 285 points (high level of quality of life), and 57—low level of quality of life. Examining patients using psychodiagnostic methods, the degree of dissatisfaction with social achievements in the main spheres of life was determined, where 5 is a high level of frustration, and 1 is low. Individual-typological characteristics, where the indicator of 9 points—expresses maladjustment of the individual. The main coping strategy was determined using 8 subscales.

Literature Review

The study of paranoid delusions as a complex psychopathological phenomenon has evolved through the integration of neurobiological, psychological, and social approaches. According to the International Classification of Diseases (*2022*), paranoid delusion syndrome may occur within the spectrum of schizophrenia, delusional disorder, or paranoid personality disorder, representing a multifactorial pathology that challenges precise diagnostic categorisation (*International Classification…, 2022*). Recent research underscores that while delusions and hallucinations are traditionally viewed as productive symptoms of psychosis, the stability and resistance of paranoid delusions to correction reveal their profound roots in both biological and experiential determinants (*Borozenets et al., 2020*; *Napreyenko, 2019*).

Scholars such as Zimmerman (*2021*) and Casarella (*2020*) emphasise that PPD is distinguished by deeply ingrained patterns of mistrust and suspicion that distort perception and cognition. This distortion results in an altered subjective reality, often accompanied by rigid defences against perceived threats. These cognitive biases are reinforced by emotional dysregulation, forming a persistent maladaptive schema that defines the paranoid worldview. Empirical studies confirm that individuals with PPD exhibit impaired insight and interpretive flexibility, which complicates differential diagnosis from schizophrenia spectrum disorders (*Zimmerman, 2021*).

From a neurobiological standpoint, researchers have explored the dysfunctions of neurotransmission and neuroendocrine regulation as critical in the formation of paranoid symptoms. Deisenhammer, Zetterberg, and Fitzner (*2019*) highlighted those disturbances in cerebrospinal fluid biomarkers in patients with schizophrenia and related psychoses reflect altered immune and neurochemical activity, influencing thought organisation. Complementing this, Mikulska et al. (*2021*) proposed that the dysregulation of the hypothalamic–pituitary–adrenal axis contributes to chronic stress reactivity, exacerbating paranoid ideation. These biological models support the assumption that paranoia arises from an intersection of neurophysiological instability and cognitive overinterpretation of threat.

A significant body of literature also addresses the comorbidity between paranoid delusions and affective or addictive disorders. Studies by Fedorchuk et al. (*2020*) and Gannon et al. (*2019*) suggest that maladaptive coping mechanisms and physiological arousal may reinforce paranoid patterns, particularly among individuals with substance use histories or anxiety–depressive

tendencies. This supports the biopsychosocial model, in which paranoia represents a defensive adaptation to chronic stress or trauma rather than a purely endogenous psychosis. Similarly, Craske, Meuret, and Ritz (*2019*) demonstrated that therapeutic modulation of affect and anxiety through positive affect treatments can reduce the intensity of delusional interpretations, showing the importance of emotional regulation in psychotherapeutic intervention.

Environmental and socio-economic determinants also play a substantial role in the development and persistence of paranoid delusions. Kalin (*2021*) and Mikulska et al. (*2021*) showed that urban density, economic hardship, and prolonged social stress correlate with a higher prevalence of delusional experiences. In urban environments, excessive sensory stimulation and social anonymity amplify cognitive distortions and hypervigilance (*Mikulska et al., 2021*). Epidemiological evidence indicates that paranoid delusions are equally frequent in developed and developing countries, yet the manifestations are more acute in populations exposed to extreme deprivation and instability (*Sall et al., 2019*).

From the perspective of developmental psychology, many authors trace paranoid formations to early experiences of mistrust and emotional neglect. Tibber, Kirkbride, and Mutsatsa (*2019*) identified socio-environmental factors such as familial dysfunction and bullying as precursors of paranoid traits in adolescence. Safai (*2022*) expanded this developmental typology by proposing five types of paranoid personalities—narcissistic, antisocial, compulsive, passive-aggressive, and decompensated—each of which reflects maladaptive responses to unmet childhood expectations and the internalisation of parental criticism. These findings suggest that early emotional deprivation and punitive upbringing form the psychological substrate for adult delusional ideation.

Further, studies by Hinojosa-Marqués et al. (*2021*) and Cosgrave, Purple, and Haines (*2021*) reveal the interpersonal mechanisms through which paranoia perpetuates itself. Using family-based and computational simulation methods, they demonstrated that individuals with paranoid delusions often externalise shame and blame, thereby provoking social rejection that confirms their negative expectations. This cyclical reinforcement of suspicion and isolation constitutes a key mechanism of chronicity. Paranoid cognition thus functions as a self-maintaining feedback system that converts interpersonal anxiety into delusional conviction.

The research of Zhyvaho (*2021*) and Stavytska et al. (*2021*) contributes to understanding the psychosocial dimensions of treatment and rehabilitation. Their studies show that low life satisfaction, frustration in family and social relations, and reduced emotional resilience are common among patients with paranoid delusions. Psychodiagnostic assessments using instruments such as WHOQOL-SM and the Wasserman-Boyko frustration scale indicate that these individuals experience pervasive deficits in social adaptation, often correlated with rigid and introverted personality structures. Consequently, therapeutic strategies must focus not only on pharmacological correction but also on restoring patients' capacity for trust and social interaction.

In sum, the literature highlights paranoid delusions represent a multidimensional construct encompassing biological vulnerability, cognitive distortions, and social maladjustment. The convergence of findings from psychiatry, psychology, and neuroscience supports a unified view of paranoia as a complex adaptive failure shaped by both internal and environmental determinants (*Musliner et al., 2019*; *Pugle, 2021*). The integration of these perspectives forms the

foundation for developing diagnostic frameworks capable of distinguishing paranoid personality disorder from schizophrenia and related psychoses, thereby enhancing treatment precision and clinical outcomes.

Results

In psychiatric practice, the presence of two independent diagnoses in a patient, which can be distinguished separately from each other, belongs to the category of comorbid diseases. Schizophrenia is sometimes combined with somatic diseases and mental disorders, which greatly complicates the effectiveness of treatment. In this study, 5 comorbidities were identified in the anamnesis of the patients' diseases that form a common symptom complex of schizophrenia or vice versa, become concomitant disorders in schizophrenia. After analysing the control cards of dispensary care for patients with mental disorders, the most common addictive disorders suffered by the patients were determined. The list of non-chemical means includes: tobacco, tea, coffee, alcohol, watching TV shows/series, computer games, food, and Internet abuse. There were rare cases of workaholism, gambling, and oniomania. Among psychoactive substances of chemical origin, opioids, psychostimulants, and sedatives prevailed. The article aims to determine which of the researched disorders has the most pronounced symptoms of paranoid delusions, and whether this syndrome can be separated into paranoid personality disorder. For this, a number of diagnostic techniques were conducted with the respondents, the results of which are given below (*Figure 1*).

It is known that persons with affective disorders, psychoses and those who abuse psychoactive substances have a fairly high level of suicidal risk. Suicidal thoughts are also characteristic of patients with schizophrenia, however, only patients with persecutory delusion resort to decisive actions. According to the results of diagnosis on the suicidal risk scale of the American Association of Suicidology (*Syropyatov et al., 2021*) managed to identify a group of patients with characteristic suicidal symptoms (*Figure 2*).

Therefore, according to the indicators presented in Figure 2, it can be concluded that the largest number of patients with a high tendency to suicide is a personality disorder. According to 4 modules of the suicidal risk scale of the American Association of Suicidology (*Syropyatov et al., 2021*), patients with this disorder have the highest indicators, especially according to the modules "suicidal behaviour" and "potential danger of suicidal attempts". Answers in these two scales can be given only by mentally ill patients who have had unsuccessful suicide attempts or typical preparatory measures.

With the help of a special module for patients with endogenous psychoses WHOQOL-SM (*Zhyvaho, 2021*), the level of perception of the quality of life by patients was investigated (*Figure 3*). Thanks to this psychometric technique, it was possible to determine the general level of subjective perception of the quality of life and the spheres affecting this indicator. The vast majority of patients have low indicators in the field of positive and negative emotions, which indicates difficulties in determining their emotional state in schizophrenia. The sphere of own functioning (cognitive capabilities, abilities to perform work and everyday tasks) also has low indicators. The spheres of recreation and entertainment, professional and family status, social interaction and support also have low indicators. High indicators could not be found in any sphere, which indicates the patients' dissatisfaction with the quality of their lives.

The results shown in Figure 3 confirm the data of the psycho-diagnostic examination according to the method of diagnosing the level of social frustration of L.I. Wasserman in the modification of V.V. Boyko (*Figure 4*) (*Stavytska et al., 2021*). Therefore, all respondents have an increased level of frustration: patients with a depressive disorder have frustrations in the field of "cognition" and "happy family life"; patients with schizophrenia who have compatible addictions showed a high level of frustration in "material support of life"; patients with comorbid mental disorders in schizophrenia—obsessive-compulsive disorders have a high level of frustration in the areas of "freedom", "having friends", "happy family life"; schizophrenic patients with personality disorder have a high level of frustration in the sphere of "love", "having friends", "happy family life"; in patients with anxiety-phobic disorders, the spheres of "material support of life" and "happy family life" are frustrated. Therefore, it can be concluded that patients are dissatisfied with the quality of their lives due to the inability to establish relationships with people, which is why they lose the opportunity to create a family, have friends, and improve their financial situation.

The final method, which allowed creating the portrait of a person with a mental disorder of paranoid delusions, is the method of determining the typological features of the personality and leading character traits of L.M. Sobchyk (*Figure 5*) (*Stavytska et al., 2021*). With the help of this technique, the author was able to determine the leading trends in the development of the individual in the process of interaction of his "Me" with the social environment. So, according to Figure 5, it can be seen that some comorbid mental disorders in schizophrenia have maladaptive properties: in depressive disorder, these are "introversion" and "anxiety", that is, such patients are prone to isolation and alienation from the environment due to obsessive fears and panic reactions. In patients with addictive behaviour, "extraversion" is a maladaptive property. They have indecipherable social relationships, trying to solve their problems at the expense of other people. In patients with obsessive-compulsive disorder, "spontaneity", "sensitivity" and "anxiety" have maladaptive properties, that is, the neurotic state of such people consists in impulsive actions on which the patient spends all his resources.

Patients with schizophrenia and personality disorder showed maladaptive properties according to the parameters' "rigidity", "introversion", "anxiety" and "lability", that is, obsessive fears in combination with alienation form wariness and suspicion, in addition, the persistence of such people in their beliefs can lead to steroid manifestations. This means that personality disorder is the most widespread comorbid mental disorder in schizophrenia according to individual typological characteristics. Patients with anxiety-phobic disorders showed maladjustment in the properties of "introversion" and "anxiety". From the anamnesis, the patients were determined to have the following list of phobias: agoraphobia, specific isolated phobias, generalized anxiety disorder, and social phobias. These phobias form their individual typological characteristics, which consist of obsessive fears and panic reactions, a tendency to isolation, and alienation from the environment.

Confirming the results obtained during the examination according to the individual-typological questionnaire L.N. Sobchyk (*Stavytska et al., 2021*), patients with comorbid mental disorders in schizophrenia choose a certain way of behaviour in a stressful situation to overcome difficulties (*Figure 6*).

Therefore, 70% of patients with a comorbid mental disorder in schizophrenia—depressive disorder has coping "taking responsibility". This coping is considered the most ecological way to solve the problem, however, in combination with the maladaptive character trait "anxiety", such people try to solve the problem to avoid punishment. Copings "escape-avoidance" and "planning" are characteristic of schizophrenia patients with addictions. This choice of coping is explained by the desire to "escape" from problems by choosing any type of addiction. And from the outside, such patients show a desire to get rid of a bad habit (they turn to a therapist, take medication), however, the negative symptoms of schizophrenia lead to new exacerbations. Only correct treatment of schizophrenia allows the patient to get rid of addictions. Patients with obsessive-compulsive disorder in schizophrenia have several coping strategies, the course of the disease burdened by the symptoms of schizophrenia requires efforts to regulate their feelings and actions, search for emotional support from the outside, solve problems to avoid punishment, plan their behaviour to control their actions and focusing on a positive assessment of the environment.

Patients with schizophrenia personality disorder choose to distance themselves from a stressful situation by making both behavioural and cognitive efforts. That is, the psyche of such people seeks to displace negative experiences, considering the maladaptive properties of the character (*Figure 5*). Such patients have an individual type of experience, which consists in creating their world-view, in which the patient shows his strengths and direction of motivation, style of relationships, and cognitive processes. Patients with anxiety-phobic disorders in schizophrenia, considering their individual and typological personality characteristics (*Figure 5*), resort to efforts to regulate their feelings and actions: they are in co-dependent relationships to receive emotional support; arbitrarily focused efforts to solve problems to avoid punishments; behavioural efforts aimed at escaping from problems.

Summarizing all of the above, it was possible to identify a comorbid mental disorder in schizophrenia, which, according to its symptoms and features of manifestation in the environment, has the aetiology of paranoid delusions, namely, personality disorder in schizophrenia. In the anamnesis of patients with comorbid personality disorders in schizophrenia, demonstrative and anxiety disorders prevailed; emotionally unstable and anankast—in smaller numbers. According to the symptoms, these disorders were divided into a separate group and a treatment protocol was applied to such patients, according to it the negative symptoms of schizophrenia are reduced. However, during the treatment, which was performed in a psychiatric clinic in outpatient conditions, the condition of the patients remained unchanged. The table (*Table 1*) summarizes all the symptoms of personality disorder in schizophrenia, which indicates the features of the manifestation of paranoid delusions.

So, in patients with paranoid delusions, such features of manifestation can be identified, which, with a complete symptom complex, can be distinguished as a personal mental disorder. It is noted that against the background of common symptoms that have been diagnosed in patients with other mental disorders in schizophrenia, the personality disorder is distinguished by such individual-typological features as rigidity and lability. The level of these properties beyond the norm is manifested in the inertia of judgments, wary suspicion, demonstrativeness and hysterical manifestations. That is, in the world-view of such a person, the entire environment is perceived as hostile, from which it is necessary to protect. Usually, such patients

do not pose a threat to society, because there is no aggressiveness in their symptom complex. Suicide can be committed accidentally (in a state of affect, when it is difficult for the patient to control his emotions) or demonstrative suicide. The latter most often occurs against the background of delusions of persecution, when the patient harms himself to confirm his false ideas to convince others of the truth of his ideas.

Discussion

It is required to understand that at the basis of paranoid delusion lies psychological violence that occurred in childhood. Such events change the stereotype of thinking in the direction of negative judgments. Therefore, the symptoms of paranoid delusions are affected by both the personal characteristics of a person and the negative effects of the environment. From the research conducted in this article, it can be seen that two types of comorbid mental disorders in schizophrenia: obsessive-compulsive and anxiety-phobic have similar symptom complexes to personality disorder in schizophrenia, however, in the structure of these disorders, there are no such positive symptoms of schizophrenia as delusions, hallucinations, feelings own greatness, hostility and suspicion, as well as negative symptoms: disorders of abstract thinking. Paranoid delusions are also absent in comorbid psychiatric depressive disorders and various addictions in schizophrenia. Therefore, diagnosing the features of the manifestation of paranoid delusions causes certain difficulties, because in practical and scientific terms there are not enough diagnostic criteria for determining this mental illness. In modern studies of mental disorders of the personality, it was found that about 1–2% of patients have signs of paranoid delusions (*Sall et al., 2019*). Moreover, this indicator is the same both for developed countries and for the Third World countries. In a study by J. Gannon et al. (*Gannon, et al., 2019*) in European countries, 1 patient with paranoid delusions was found out of 1000 respondents, as well as in African and Asian countries. The only difference is that the pathogenesis of the disease in the Third World countries develops faster and manifests itself in acute states of confused consciousness.

The socio-economic factor affects the spread of paranoid delusions among low-income segments of the USA population. The author of this study, N. Kalin (*2021*), explains the high level of stress experienced by people from disadvantaged regions. The incidence of paranoid delusions increases in direct proportion to the number of the city's population. J. Mikulska et al. (*2021*) conducted a study in British cities with a population of over 100,000 people and found that cities with crowded streets, public transport and leisure facilities make some individuals want to be secluded. There are scientists who insist on the genetic aetiology of the disease, but the gene itself has not yet been identified (*Musliner et al., 2019*; *Pugle, 2021*). However, in the research of this article, it is noted that this personality disorder is acquired and has become a kind of protective mechanism against stressful events, e.g., the negative treatment of parents with their children: the absence or insufficient satisfaction of basic needs and psychological violence. In this way, an adult by the age of 20–25 develops a basic sense of mistrust of the world, they expect sadistic behaviour from people in the environment, show dependence in relationships or generally avoid them to protect themselves. Such assumptions are confirmed in the research of M. Tibber et al. (*2019*), where they consider this disorder as a trust deficit. Because of this, patients tend to exaggerate any barely noticeable actions of the environment and perceive them as hostile and can react intensively to them. These beliefs become part of the

patient's awareness of the influence of others on her. O. Napreyenko (*2019*) in his study explained this by the presence of alexithymia, the presence of which in the anamnesis of patients causes disturbances in relationships with people, difficulties in social adaptation and even autism.

In his research, Y. Safai (*2022*) also proves that paranoid delusion occurs in combination with other personality disorders. Y. Safai distinguishes 5 types of paranoid personalities with delusional syndrome. "Paranoid-narcissistic" manifests itself as megalomania with underdeveloped social skills. The author explains that these patients, facing an obstacle in an environment that does not recognize the omnipotence of the patient, plunge into their fantasy world and dream about their greatness there. "Paranoid-antisocial" perceives the surrounding world as hostile and responds to it with rebellious behaviour, pushing other people away from themselves. "Paranoid-compulsive"—perfectionists, self-critical, behave alienated. Tend to attribute personal shortcomings to others. "Paranoid-passive-aggressive"—irritable, negative, unable to maintain strong relationships (delusions of jealousy), socially isolated. The "decompensated" type of paranoid disorder manifests itself in psychotic episodes as a response to stress, which can later develop into psychosis.

The reason for the formation of these types is explained by Y. Safai (*2022*) in the peculiarities of raising a child, namely, the attitudes transmitted by parents to their children: "You must meet our expectations: be afraid of mistakes, not be different from others." As a result of such upbringing, a personality is formed, dependent on the opinion of the environment with broken social ties, very often becomes a victim of bullying in the children's team. Spending a lot of time in thought (especially in adolescence), such people develop a sense of loneliness, and the psyche, trying to save the individual from obsessive thoughts, forms an awareness that the cause of bullying lies in its peculiarities and envy of others. Such a defence mechanism is believed to alleviate suffering; however, delusions of grandeur reinforce social isolation and social interactions cause anxiety. Therefore, a person suffering from paranoid delusions has an internal conflict, which is depicted in Figure 4—spheres of the social environment that cause frustration (not meeting needs). And, therefore, patients want to have a family, friends, a loved one, a favourite job, however, acceptance by others will threaten the patient's system of ideas about the surrounding world, which increases a person's social isolation.

In study, L. Hinojosa-Marqués et al. (*2021*) studied the responses of a patient with paranoid delusions during a psychiatric interview using the method of computer simulation of responses developed by E. Colby in 1981. This model is based on a set of strategies that patients use to avoid shame and humiliation. L. Hinojosa-Marqués et al. investigated that the self-esteem of a person with a personality disorder who has paranoid delusions is based on the idea that he is flawed, imperfect, inadequate. When such people find themselves in a humiliating situation for them, there is a protective reaction of the psyche—to shift the blame to others, even if this situation was created by the person with a mental disorder. By taking potentially offensive measures against people it attributes bad deeds to, one can get the same appropriate measures in return. Thus, a person suffering from paranoid delusion disorder personally increases shame and humiliation without realizing it. Feeling anger and anxiety is more acceptable for such people than shame and humiliation. In the study of J. Cosgrave et al. (*2021*) confirms the assumption that the set of symptoms that characterize paranoid delusions is a personality

disorder. J. Cosgrave et al. specify that paranoid delusions include thought disorders and found that 2.2–4.4% of USA residents have social anxiety disorder.

Diagnosing paranoid delusions and establishing the causes of development requires professional skill from a psychiatrist. Patients do not often seek treatment on their and tend to spread their delusional ideas to the doctor. Long-term, systematic delirium makes it difficult for the patient to stay in the team, and therefore the medical staff can be perceived as hostile. Therefore, it is very important that the atmosphere in the medical institution is favourable and does not cause hostility. With competent treatment, the patient can get rid of symptoms or their manifestation will decrease. The complexity of such treatment lies in the responsibility borne by the patient, and when treatment is refused, the mental disorder progresses. The pathogenesis of some cases has an unfavourable prognosis, for example, patients with concomitant organic lesions of the central nervous system, chronic diseases and various types of addiction.

Conclusions

The prevalence of mental disorders among the population is a serious problem that requires an immediate solution. The development of the symptoms of some diseases takes several years, so the separation of paranoid delusions into a separate nosological unit allowed studying this disease in more detail and objectively. The best way to diagnose a personality disorder with paranoid delusions is when the stage of systematic delusions is formed. During this period, the patient associates him with the environment, which worsens relations in the family and at the workplace. Timely combined treatment stabilizes mental activity and reduces the expression of pathological symptoms, which ensures the normalization of social relations. In the absence of appropriate treatment, systematized delirium progresses and sometimes pushes the patient to commit criminal acts against the environment. However, in the research of this article, it is noted that aggressiveness is not a characteristic feature of persons with paranoid delusions. For them, rigidity and lability are more inherent—two opposite signs that form an internal personality conflict: there is a natural desire to build relationships with the surrounding world, however, they will have to get rid of their illusion about the hostility of the environment. Therefore, patients tend to independently create potentially criminal activities to approve their world-view and convince others of it.

Paranoid delusions are a component of a personality disorder, and in this study, criteria were identified by which the features of this syndrome can be determined: delusions, disorganization, suspiciousness; emotional and social alienation, limitation of contacts, apathy, stereotyped thinking; one's own life is perceived as of low quality; happy family life, having friends and love are areas in which patients feel frustrated; anxiety, introversion, rigidity, and lability—individual and typological characteristics of patients with personality disorder with schizophrenia; distancing, escape-avoidance—behavioural strategies in stressful situations. Therefore, the prospect of further research consists in obtaining reliable data for understanding the essence of personality disorders with paranoid delusions, for this it is necessary to experimentally determine the diagnostic minimum that fully characterizes the features of the manifestation of paranoid delusions.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Borozenets, A., Dumchev, K., Zlydenny, T., Ivanchuk, I., Kabanchyk, M., Kolomiets, V., & Pinchuk, I. (2020). Mental and behavioral disorders (addiction syndrome) as a result of opioid use. Clinical guideline. *Public Health Alliance*, *5*(3), 25–28.

Casarella, J. (2020). Delusions and Delusional Disorder. *WebMD Editorial Contributors*. https://www.webmd.com/schizophrenia/guide/delusional-disorder

Cosgrave, J., Purple, R. J., & Haines, R. (2021). Do environmental risk factors for the development of psychosis distribute differently across dimensionally assessed psychotic experiences? *Translational Psychiatry, 11*(20), 226–231.

Craske, M., Meuret, A., & Ritz, T. (2019). Positive affect treatment for depression and anxiety: A randomized clinical trial for a core feature of anhedonia. *Journal of Consulting and Clinical Psychology*, *87*(5), 457–471.

Deisenhammer, F., Zetterberg, H., & Fitzner, B. (2019). The cerebrospinal fluid in multiple sclerosis. *Frontiers in Immunology*, *10*(33), 89–96.

Fedorchuk, S., Ivaskevych, D., Borysova, O., Kohut, O., Marynych, V., Tukaiev, S., & Petrushevskyi, I. (2020). Coping strategies in connection with psychophysiological characteristics of skilled female handball players. *Bulletin of National University of Physical Education and Sport of Ukraine*, *2*(8), 315–322.

Gannon, J., Brar, J., Rai, A., & Chengappa, K. (2019). Effects of a standardized extract of Withania somnifera (Ashwagandha) on depression and anxiety symptoms in persons with schizophrenia participating in a randomized, placebo-controlled clinical trial. *Annals of Clinical Psychiatry*, *31*(2), 123–129.

Hinojosa-Marqués, L., Monsonet, M., Kwapil, T. R., & Barrantes-Vidal, N. (2021). The impact of family environment on self-esteem and symptoms in early psychosis. Maastricht. *PLoS ONE*, *16*(4), 49–72.

International Classification of Diseases 11th revision. (2022). *World Health Organization*. https://icd.who.int/en

Kalin, N. (2021). Depression and Schizophrenia: Sleep, Medical Risk Factors, Biomarkers and Treatment. *American Journal of Psychiatry*, *178*(10), 881–884.

Mikulska, J., Juszczyk, G., Gawrońska-Grzywacz, M., & Herbet, M. (2021). HPA axis in the pathomechanism of depression and schizophrenia: new therapeutic strategies based on its participation. *Brain Sciences*, *11*(10), 1298.

Musliner, K., Mortensen, P., & McGrath, J. (2019). Association of polygenic liabilities for major depression, bipolar disorder, and schizophrenia with risk for depression in the Danish population. *JAMA Psychiatry*, *76*(5), 516–525.

Napreyenko, O. (2019). Schizophrenia: causes, features of manifestation and treatment. *Psychiatry*, *2*(3), 10–19.

Pugle, M. (2021). What Is Paranoia? *Very Well Health*. https://www.verywellhealth.com/paranoia-5113652

Safai, Y. (2022). Paranoia and schizophrenia: What you need to know. *Medical News Today*, *5*(3), 37–43.

Sall, J., Brenner, L., & Millikan, B. (2019). Assessment and Management of Patients at Risk for Suicide: Synopsis of the 2019 U.S. Department of Veterans Affairs and U.S. Department of Defense Clinical Practice Guidelines. *Annals of Internal Medicine*, *171*(5), 343–353.

Stavytska, S., Sydorenko, O., Stavytskyi, G., Otych, D., & Fedorenko, A. (2021). *Methodological recommendations for conducting educational psychodiagnostic practice for students of specialty 053 "Psychology", educational degree "Bachelor"*. Kyiv: Department of the NPU named after M.P. Drahomanova.

Syropyatov, O., Dzerzhunska, N., Drevitska, O., Gorshkov, O., Butska L., Mazhbits, V., & Marushchenko, K. (2021). Organizational and medico-psychological measures to prevent suicidal behavior in the army. *International Scientific Journal "Grail of Science", 2*(3), 516–525.

Tibber, M., Kirkbride, J., & Mutsatsa, S. (2019). Are socioenvironmental factors associated with psychotic symptoms in people with first-episode psychosis? A cross-sectional study of a West London clinical sample. *BMJ*, *10*(11), 30–44.

Zhyvaho, Kh. (2021). The use of psychotropic drugs in the complex of measures of medical and social rehabilitation of patients with paranoid form of schizophrenia with depressive symptoms. *Psychological Health*, *1*(6), 92–101.

Zimmerman, M. (2021). Paranoid personality disorder (PPD). *Medical Review*, *5*(6), 12–19.

Appendix

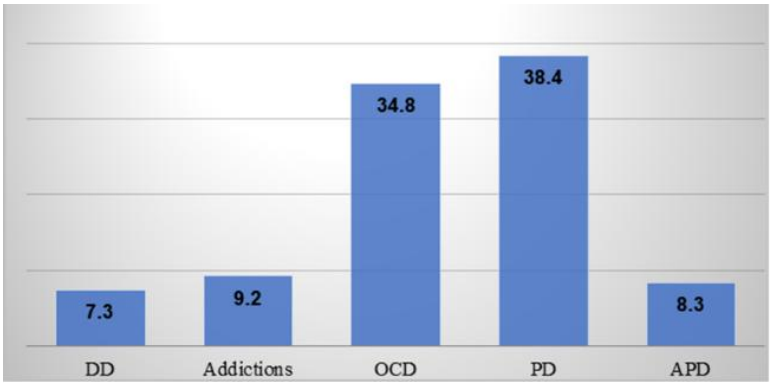

Figure 1. Results of a diagnostic examination using the psychometric method Positive and Negative Syndrome Scale

Note: DD—depressive disorder, OCD—obsessive-compulsive disorder, PD—personality disorder, APD—anxiety-phobic disorder.
Source: the author created the material based on (Napreyenko, 2019).

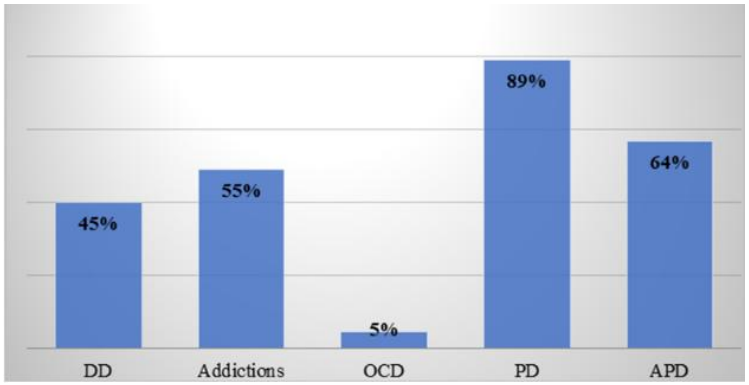

Figure 2. Diagnostic results according to the suicidal risk scale of the American Association of Suicidology

Note: DD—depressive disorder, OCD—obsessive-compulsive disorder, PD—personality disorder, APD—anxiety-phobic disorder.
Source: the author created the material based on (Syropyatov et al., 2021).

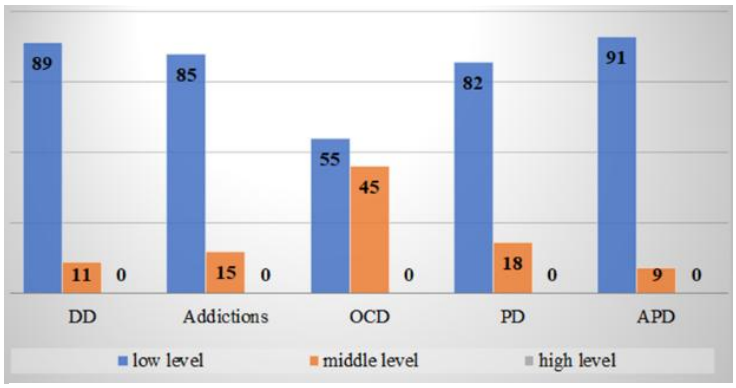

Figure 3. Diagnostic results according to the special module for patients with endogenous psychoses WHOQOL-SM (%)

Note: DD—depressive disorder, OCD—obsessive-compulsive disorder, PD—personality disorder, APD—anxiety-phobic disorder.

Source: the author created the material based on (Zhyvaho, 2021).

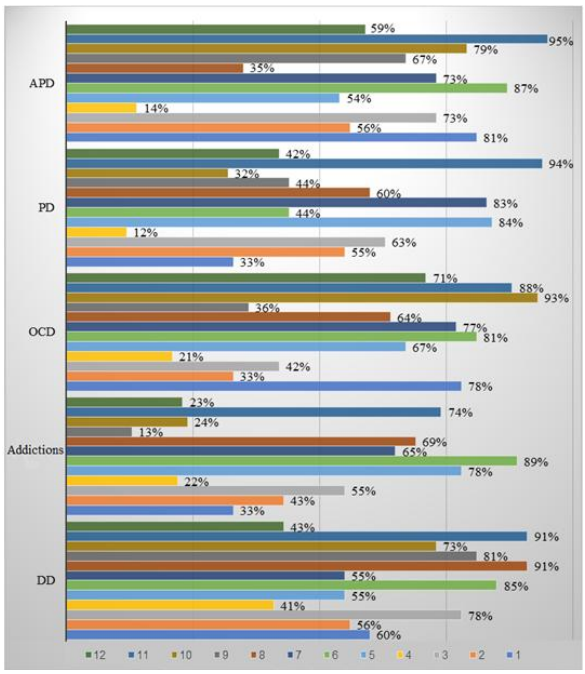

Figure 4. Results diagnosis of the level of social frustration according to the method of L.I. Wasserman in the modification of V.V. Boyko

Note: 1—active life; 2—health; 3—interesting work; 4—beauty of nature and art; 5—love; 6—material support of life; 7—presence of friends; 8—self-confidence; 9—cognition; 10—freedom; 11—happy family life; 12—creativity; DD—depressive disorder, OCD—obsessive-compulsive disorder, PD—personality disorder, APD—anxiety-phobic disorder.

Source: the material was compiled by the author based on (Stavytska et al., 2021).

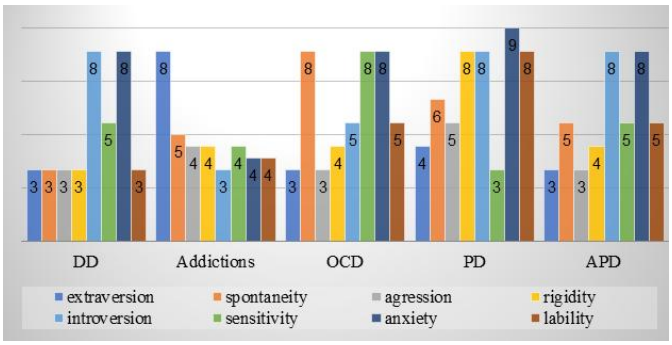

Figure 5. Results of the psychodiagnostic examination according to the individual-typological questionnaire L.N. Sobchyk (%)

Note: DD—depressive disorder, OCD—obsessive-compulsive disorder, PD—personality disorder, APD—anxiety-phobic disorder.
Source: the material was compiled by the author based on (Stavytska et al., 2021).

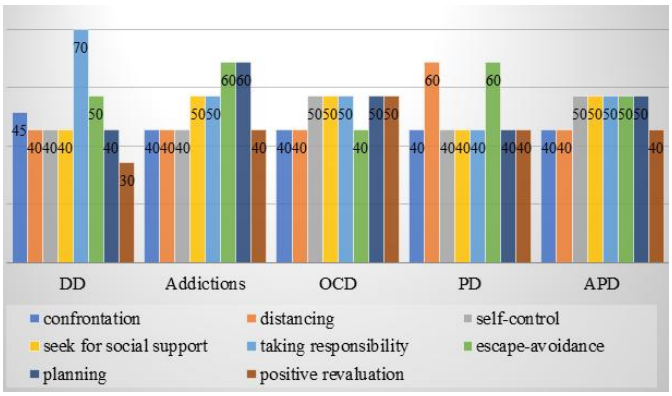

Figure 6. The results of a psychological study of the choice of behavioural strategies (%) according to the coping questionnaire Ways of Coping Questionnaire R. S. Lazarus, S. Folkman

Note: DD—depressive disorder, OCD—obsessive-compulsive disorder, PD—personality disorder, APD—anxiety-phobic disorder.
Source: the material was compiled by the author based on (Fedorchuk et al., 2020).

Table 1. Generalized data on the characteristics of the manifestation of paranoid delusions in personality disorder in schizophrenia

Symptom	Features of manifestation
Positive/negative symptoms of schizophrenia	Delirium, disorganization, suspiciousness
Suicidal behaviour	Emotional and social alienation, limitation of contacts, apathy, stereotyped thinking
Subjective perception of the level of quality of one's own life	The quality of one's own life is perceived as low
The level of social frustration	A happy family life, having friends and love are areas in which patients feel frustrated
Individual typological features	Anxiety, introversion, rigidity, and lability are individual and typological characteristics of patients with a personality disorder with schizophrenia
Style of coping strategies	Distancing, escape-avoidance—behavioural strategies in stressful situations

Source: the author compiled the material.

Taras Bondar [a][9], *Viktor Holub* [b][10], *Diana Melnyk* [c][11]

Rationale for the Invariant Content of Physical Education in the Context of Inclusive Education [8]

Abstract: In recent years, there has been a dynamic increase in the number of students with special educational needs (SEN) in educational institutions. However, as evidenced by the analysis of scientific and methodological literature, anomalies in the physical development of such children remain largely unexplored. This significantly complicates the development of physical education curricula, hinders the effective adaptation and modification of existing educational programs, and prevents the creation of effective individualized development programs for students with SEN. Therefore, to address this issue, there is a need to study empirical data on the physical development of children with SEN and to justify the invariant content of educational programs for this population. During the 2024–2025 academic year, 103 children with special educational needs were examined. The study assessed the level of development of motor coordination, balance, fine and gross motor skills, as well as abnormalities in gait patterns, posture, and the structure of the lower limbs. In addition, medical records and comprehensive assessment reports from the Kremenets Inclusive Resource Center were analyzed. The collected data were summarized in tables, statistically processed using the IBM SPSS software, and visualized through diagrams. The vast majority of students with SEN exhibited deviations in the development of both fine and gross motor skills, as well as impairments in motor coordination and balance. Furthermore, there was a high prevalence of postural disorders, structural defects of the feet, and improperly formed gait patterns. An additional issue is the difficulty in perceiving educational content, particularly instructions and explanations for motor tasks. Based on the data obtained during the study regarding physical development anomalies in learners with special educational needs (including deviations in fine and gross motor skills development, impaired coordination and balance, postural disorders, anomalies in foot structure, and gait abnormalities), a conceptual framework has been proposed for the content of an invariant module within adapted and modified individual educational programs for learners with SEN. This framework encompasses instruction and application of exercises aimed not only at facilitating children's social integration within the community, but also at enhancing motor activity and addressing the identified physical development deviations across all categories of educational difficulties.

Keywords: inclusive education, physical culture, physical education, special educational needs.

Abbreviations:

IRC is the inclusive-resource centre,

SEN is special educational needs.

Introduction

The issue of teaching and educating children with SEN is not new to pedagogical science. For a long period, the educational process for this category of learners was performed in isolation from the mainstream educational environment—mainly in specialised schools or boarding institutions. The prevailing model of such education was primarily aimed at the

[a] Candidate of Sciences in Physical Education and Sports (Ph.D.), Senior Lecturer, Department of Theory and Methodology of Physical Education, Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy. Kremenets, Ukraine.
[b] Candidate of Sciences in Physical Education and Sports (Ph.D.), Associate Professor, Head of the Department, Department of Theory and Methodology of Physical Education, Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy. Kremenets, Ukraine.
[c] Director, Municipal Institution "Inclusive Resource Centre of Kremenets City Council". Kremenets, Ukraine.

formation of basic life and elementary learning skills, often without considering the need for socialisation, integration, and the comprehensive development of the child (*Poroshenko, 2019*). At the same time, practice has demonstrated the low effectiveness of this model in the context of the constant increase in the number of children with SEN.

The global educational community responded to the necessity of creating conditions to ensure equal access to quality education for all participants in the educational process (*Hryshchenko, 2024*): in 1994 the Salamanca Statement was adopted (*Yefimenko & Moha, 2022*). In the context of Ukrainian educational policy, inclusive education began to be systematically implemented with the adoption of the revised Law of Ukraine "On Education" (*2017*) and the Law of Ukraine "On Complete General Secondary Education" (*2020*), which established the main legal framework for inclusive learning. At the same time, the Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Regulation on the Inclusive Resource Centre" (*2017*) was passed, defining the mechanisms for specialists' work on comprehensive assessment and identification of individual educational needs of learners with SEN. This was followed by the Resolutions of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for the Organisation of Inclusive Education in General Secondary Education Institutions" (*2021*) and "On Approval of the Procedure for the Organisation of Inclusive Education in Pre-School Education Institutions" (*2019*).

Such steps by the state represent a logical response to the dynamic growth in the number of learners with special educational needs (*Inclusion…, n.d.*; *Development…, 2024*). In particular, according to official statistics, in 2019 the number of such children in pre-school and general secondary education institutions amounted to 29,733, while by 2024 it had reached 51,639, indicating an increase of 73.7% (*Statistical data…, n.d.*). This means that as of 2024, for every thousand learners there are approximately 13 children with SEN (1.3%), and this trend is showing steady positive growth. At the same time, the issue of inclusive education from the perspective of psychology, speech therapy, and corrective pedagogy has been widely covered in academic publications. However, the substantiation and rethinking of the content of physical education curricula for learners with SEN, as well as the adaptation or modification of learning material, remain insufficiently explored.

At present, educational institutions, guided by the conclusions of inclusive resource centres, independently carry out the adaptation or modification of standard physical education curricula. Yet, in most cases, such changes are fragmentary, lack a scientifically grounded approach, and often amount to a formal fulfilment of requirements. Moreover, there are no unified invariant (compulsory) components in the content of physical education for learners with SEN, which makes it impossible to ensure systematic and high-quality learning (*Bondar & Melnyk, 2025*).

An analysis of current academic and methodological literature confirms the underdevelopment of this issue. For example, O. Forostian (*2018a*) notes the near absence in Ukraine of academic research devoted to the organisation and delivery of physical education lessons in inclusive classes (*Forostian, 2018a*). In our previous studies, we also emphasised the difficulties of implementing physical education in inclusive environments within general secondary schools (*Bondar et al., 2024*).

Researchers such as L. Borysenko (*2018*), O. Shukatka, and O. Korzhan (*2022*) draw attention to the prevailing scepticism among specialists regarding the effectiveness of inclusive

education specifically in physical education, which is due to the significant variability of motor impairments in children with SEN (*Borysenko, 2018*; *Shukatka & Korzhan, 2022*). A. Solovey, M. Yaroshyk, and M. Danylevych (*2025*) in their work also emphasise the ongoing debate on the content of inclusive physical education and propose a justification for the content of physical education in general secondary schools for children with autism spectrum disorders (*Solovey et al., 2025*).

In the works of M. Yefymenko and M. Moha (*2022*), the forms and methods of physical development of pre-school children with SEN are systematised, particularly those with musculoskeletal disorders (cerebral palsy, spinal paresis, delayed psychomotor development, etc.). However, the authors do not consider the content of curriculum material that could be integrated into standard educational programmes (*Yefimenko & Moha, 2022*; *Yefimenko, M. M., 2013*).

N. Horopakha (*2014*) studied certain aspects of organising physical education in inclusive settings, in particular the issues of continuity of learning material and individual forms of teaching. At the same time, as the researcher notes, there is significant inconsistency between educational programmes and their substantive content with regard to the physical education of learners with SEN (*Yefimenko & Moha, 2022*).

Thus, the existence of objective difficulties in the organisation of physical education in inclusive settings, the necessity of incorporating into its content exercises aimed at correcting deviations in the physical development of learners with SEN, together with the insufficient scientific development of the content of educational programmes, determine the relevance of conducting this study. We assume that by identifying and substantiating the most relevant content of the subject Physical Education for learners with SEN, the state of their physical development will be improved.

Therefore, the aim of this study is to substantiate the invariant (compulsory) content of physical education in the context of inclusive learning, based on factual data on the physical development of learners with SEN.

Materials and Methods

During the 2024–2025 academic year, we examined 103 children with special educational needs. The sample represents 22.4% of the total number of learners in the service area (460 individuals) who are registered with the Municipal Institution "Inclusive Resource Centre of Kremenets City Council" (Kremenets IRC). Accordingly, the results are presented with a 95% confidence level and a 7% margin of error (p=0.5).

The study involved assessment using standardised tests: motor coordination (finger-to-nose test and straight-line walking), balance (one-leg stance "Crane" test), fine motor skills (the "Fingers Greeting" test), gross motor skills (box test—the child steps into the box and then out of it again. The tasks are gradually made more complex by increasing the distance to the box and replacing it with a deeper one), gait (pedagogical observation), posture disorders (using a postural chart and child inspection), and lower limb deformities (footprint analysis, Navicular Drop Test). In addition, the child's medical records were examined. The data were recorded in the protocol for assessing the child's physical development. The conclusions of the Kremenets IRC concerning the comprehensive assessment of children with SEN were also studied.

The obtained data were summarised in tables, processed using the IBM SPSS software package, and visualised in the form of charts.

All official representatives signed consent forms for the processing of children's personal data in the state-prescribed format.

Literature Review

The study of inclusive education and its application in physical education has evolved significantly over the past decade. The legislative framework in Ukraine, established by the Laws "On Education" (*2017*) and "On Complete General Secondary Education" (*2020*), together with the Resolutions of the Cabinet of Ministers "On Approval of the Regulation on the Inclusive Resource Centre" (*2017*) and "On Approval of the Procedure for Organising Inclusive Learning in General Secondary Education Institutions" (*2021*), laid the legal foundation for inclusive practices, ensuring equal access to education for learners with special educational needs (SEN) (*On Education, 2017*; *On Complete General Secondary Education, 2020*; *On Approval…, 2017*; *On Approval…, 2021*). These legislative documents were preceded by international initiatives, notably the Salamanca Statement and Framework for Action on Special Needs Education (*n.d.*), which emphasised inclusive learning as a global priority.

In Ukrainian scholarship, inclusive education is increasingly viewed as a social and pedagogical condition for the adaptation of children with special needs (*Hryshchenko, 2024*). Poroshenko (*2019*) conceptualised inclusivity as a process of transforming educational systems to meet the needs of all learners, while Horopaha (*2014*) stressed the importance of continuity in physical education for preschoolers and younger pupils within inclusive settings. The institutional expansion of inclusive education is confirmed by statistics showing a 73.7% growth in the number of children with SEN in Ukrainian schools between 2019 and 2024 (*Statistical data…, n.d.*; *Development…, 2024*; *Inclusion…, n.d.*).

However, despite these advances, researchers identify significant gaps in the methodological and practical organisation of inclusive physical education. Forostian (*2018a*) underlined the lack of systematic approaches to planning and conducting physical education lessons for mixed groups. In a later collaborative work, Forostian, Sheremet, Leshchii, and Maliy (*2018b*) presented a corrective-developmental programme "Therapeutic Physical Culture" for children with hearing impairments, highlighting the therapeutic potential of targeted motor exercises. Nevertheless, such practices are rarely integrated into the broader structure of school curricula.

Several authors have focused on the psychological and physiological diversity of learners with SEN, which complicates the standardisation of physical education programmes. Borysenko (*2018*) emphasised that physical culture itself can serve as an inclusive environment that promotes socialisation and compensates for developmental disparities. Similarly, Shukatka and Korzhan (*2022*) observed that the variability of motor and cognitive impairments requires differentiated pedagogical strategies, while Solovey, Yaroshyk, and Danylevych (*2025*) proposed methodological guidelines for the physical education of learners with autism spectrum disorders. These studies collectively demonstrate the need for unified methodological foundations that would ensure adaptability without fragmenting the educational process.

Earlier pedagogical approaches by Yefimenko (*2013*) and later by Yefimenko and Moha (*2022*) developed correctional models of physical development for children with musculoskeletal and psychomotor disorders, using movement-based therapy and differentiated physical training. Their works became the scientific basis for integrating rehabilitative practices into inclusive education. Yet, as noted by Bondar, Melnyk, Holub, and Bondar (*2024*), the implementation of such models in schools remains inconsistent and often formal, as teachers lack the methodological resources and practical tools to modify physical education programmes appropriately.

Recent methodical recommendations by Bondar and Melnyk (*2025*) provide a conceptual framework for designing physical education in inclusive settings, stressing the importance of an invariant (compulsory) content that addresses both physical development and socialisation. This aligns with the global trend towards designing adaptive yet unified curricula that balance individualisation with systematisation (*Solovey et al., 2025*; *Forostian, 2018a*). Moreover, as Hryshchenko (*2024*) and Poroshenko (*2019*) underline, inclusive education must not be limited to integration; it should promote comprehensive development through pedagogical, psychological, and physiological support.

In summary, the literature reflects a transition from fragmented adaptive practices to the development of a systematic, evidence-based framework for inclusive physical education. The synthesis of normative, theoretical, and empirical studies substantiates the need for an invariant component within educational programmes for children with SEN, integrating corrective, developmental, and social functions of physical culture.

Results

As evidenced by the analysis of the specialised literature presented above, children with SEN face five types of educational difficulties, namely: intellectual, physical, physiological, learning and socio-adaptive (sociocultural) difficulties. These, in turn, are categorised across five levels of educational support (from 1 to 5). However, in this study the distribution of the obtained results by support levels is not provided. The data are synthesised only by groups of educational difficulties, as contained in the official conclusions of the comprehensive assessment of persons with SEN carried out by the Inclusive Resource Centre (*Figure 1*).

The analysis of the results presented in the diagram (*Figure 1*) shows that the largest group of children with SEN are learners experiencing learning difficulties. The 2nd group (around 1/4) of learners with SEN face socio-adaptive difficulties (*Figure 1*). The 3rd group comprises intellectual difficulties, accounting for about one 5th of those assessed. The 4th group (about 1/6) are children with functional difficulties. The smallest, 5th group are children with purely physical difficulties.

In line with the aim of the research, namely to identify invariant (mandatory) physical exercises for the design of adapted or modified educational programmes for learners with SEN, the next step of the study was to determine the most characteristic anomalies in the physical condition of such children, with the purpose of defining the components of the educational programme aimed at correcting physical development and preventing certain impairments. The results of the assessment are provided in the appendix (*Table 1*).

Overall, of the 103 children assessed, half had coordination and balance impairments; over one third had deficiencies in fine motor skills; slightly less than half had deficiencies in gross motor skills; 63.1% had posture problems; more than half suffered from flat feet, valgus-varus deformity of the feet, and in some cases limb shortening, which, as a result, led to gait anomalies in one third of the children; nearly half experienced difficulties in perceiving instructions and motor tasks; and one sixth of those assessed had problems with immunity (*Table 1*). (Given the margin of error in the data, the results concerning immunity formation will not be considered further as insignificant).

Further analysis of the results by groups of educational difficulties revealed that children with intellectual and physical difficulties were the most vulnerable in terms of physical condition (*Table 1*).

Thus, two thirds of learners with physical difficulties had problems with coordination, balance, gross motor skills, spinal deformities, foot structure, and gait. Half of them had fine motor deficiencies, while only a quarter experienced problems with understanding commands and instructions (*Table 1*).

Among learners with intellectual difficulties, 76.2% and 71.4% had, respectively, spinal deformities and movement coordination problems. The majority of such children also faced balance difficulties, anomalies in the structure of the lower limbs, and problems with understanding instructions and commands. About half of the children had deficiencies in fine and gross motor skills. Gait disturbances were observed in two out of five learners (*Table 1*).

The overwhelming majority of learners belonging to the socio-adaptive difficulties group experienced challenges in perceiving tasks and instructions. More than half had gross motor deficiencies, posture disorders, low coordination, and foot abnormalities. Two out of five had balance problems and fine motor deficiencies. One third had gait disturbances (*Table 1*).

Children classified in the functional difficulties group also displayed high rates of posture disorders—about 2/3—as well as problems in perceiving and carrying out tasks and instructions, and in movement coordination. Half had foot structure problems, while two out of five had balance issues. Meanwhile, the proportion of learners with fine and gross motor deficiencies was somewhat lower than in the previous groups—1/5 and 1/3, respectively. Additionally, one third of those assessed had gait disturbances, a figure similar to that observed in the socio-adaptive group (*Table 1*).

The final group consisted of learners classified as having "learning difficulties". Among them, high rates of spinal deformities and foot abnormalities were recorded, at 61.8% and 55.9%, respectively. By contrast, only slightly more than 1/3 had coordination and balance impairments, significantly fewer than in the previous groups. However, the proportion of learners with fine and gross motor difficulties was somewhat higher than among the children in the preceding group. Gait disturbances were observed in only 1/6, while difficulties in perceiving and following instructions and tasks were noted in just one tenth of learners (*Table 1*).

At the next stage of the study, we conducted a variance analysis of the obtained data across groups of difficulties relating to physical development disorders in children with SEN (*Figure 2*).

The analysis of the diagram presented in Figure 2 demonstrates that the smallest deviations from the mean values are observed in indicators concerning posture disorders and abnormalities

in the structure of the lower limbs (within 10–11%). This suggests that such defects are highly likely to occur in learners with SEN in the proportions presented in this study. Slightly less common (deviation within 12%) are impairments in fine motor skills. Less frequent still (15–17% deviation) is reduced development of movement coordination, balance, and gross motor skills. However, the variance analysis overall confirms the significant impact of the listed anomalies on the physical development of children with SEN as a complex problem.

Based on the data in appendix (*Figure 2*), gait abnormalities occur much less frequently (deviation from the mean of 21.2%). Even fewer children with SEN experience problems with the perception of learning material, tasks, and instructions (deviation of 25.01%).

At the final stage of the scientific substantiation for selecting invariant exercises for adapted or modified physical education programmes for learners with SEN, we carried out a correlation analysis between the groups of data and compiled a correlation matrix (*Table 2*). The data presented in Table 2 indicate that there is a high correlation between all indicators of physical development disorders as well as indicators of difficulties in perceiving instructions and tasks, ranging from 0.92703 to 0.99969, meaning that all the identified dependencies tend towards 1.

Thus, based on the above, it can be stated with high probability that learners with SEN face a complex problem concerning the formation of their bodies, regardless of the group of educational difficulties. This demonstrates the necessity of developing a unified invariant content for the physical education of such children. In our view, this will contribute to a more effective learning process and the prevention of physical development anomalies.

Discussion

Considering the research findings, it can be stated that the division of children with SEN into groups according to educational difficulties is rather conditional. The obtained data indicate that a learner is assigned to one group of educational difficulties most significant for the individual in accordance with the Regulations on the Inclusive Resource Centre (Resolution of the Cabinet of Ministers of Ukraine of 12 July 2017, No. 545). However, a child may simultaneously exhibit other educational difficulties of varying degrees. For example, a child with intellectual difficulties may also present with physical and other impairments.

Among children with SEN, a significant number of learners have deviations in physical development (deficiencies in fine and gross motor skills, disturbances in coordination and balance). In addition, many children experience postural disorders, foot structure anomalies, and gait abnormalities. This confirms the data in the scientific literature described by M. Yefimenko, A. Solovey, O. Forostian, etc. (*Yefimenko & Moha, 2022*; *Yefimenko, 2013*; *Solovey et al., 2025*; *Forostian et al., 2018b*). Some children also have difficulties in perceiving learning material through explanations and instructions for motor tasks.

Therefore, when designing adapted and modified educational programmes for learners with SEN, it is necessary to introduce an invariant component. Its content should include training in physical exercises that not only increase children's level of physical activity but are also aimed at correcting the above-mentioned anomalies of physical development. The only exception is instruction in proper gait, which should be selected individually for a child if such a developmental defect is present. The same applies to the choice of teaching methods for learners

who have difficulties in perceiving and assimilating learning material. For instance, if a child has a hearing impairment—demonstration and sign language are used; weak spatial orientation—assistance of a teaching assistant and various markings on the playground and signs; visual impairment—a system of signals; difficulties in comprehension—a slow demonstration of the exercise with explanation, and so forth.

Conceptually, the invariant content is presented below:

1. Gross motor difficulties

   Educational needs of the child—development of gross motor skills, acquisition of motor experience, mastery of basic human movements. Main physical exercises: walking (in a straight line, on heels, on toes, sideways, stepping over obstacles such as a rope or blocks, with a beanbag on the head); running on the spot; jumping (on two feet, on one foot, forwards, sideways, backwards, from standing); rhythmic exercises; symbolic and active games.

2. Fine motor difficulties

   Educational needs of the child—development of fine motor skills, mastery of precise hand movements. Main physical exercises: trays with small balls, Montessori lacing boards, games with buttons and beads (timed and untimed), rolling wooden and rubber balls with the palm on a flat surface, finger gymnastics, finger games.

3. Coordination difficulties

   Educational needs of the child—development of movement coordination, formation of movement accuracy. Main physical exercises: standing on one leg with arms outstretched, exercises with closed eyes (standing on tiptoes, bends, head turns), stepping over obstacles (ropes, cushions, small objects), throwing and catching a ball in different ways (with both hands, one hand, over the head), ball dribbling (on the spot, between obstacles), jumping with a ball, arm rotations (bent at elbows, straight), trunk rotations, circular head movements, catching falling objects, throwing objects at a target, drawing exercises.

4. Balance difficulties

   Educational needs of the child—development of balance, formation of spatial orientation. Main physical exercises: head rotations with support against the wall, side bends while standing on one leg, "Swallow" pose, balancing on a curved board, exercises on fitballs, crawling through tunnels, passing a ball between players standing on one leg, ball passing from a squatting position, dance exercises.

5. Postural difficulties

   Educational needs of the child—correction of posture, strengthening of spinal muscles. Main physical exercises: pelvic lifts in a supine position, "Cat" exercise, "Plank" exercise, wall bar exercises, forward bends from sitting and standing positions, breathing exercises.

6. Foot structure difficulties

   Educational needs of the child—prevention of flat feet, strengthening of lower limb muscles. Main physical exercises: foot rotations, walking on the spot-on different parts of the foot, rising on tiptoes, walking on the inner and outer edge of the foot, picking up pencils with toes, self-massage of the feet, walking on a massage mat.

The obtained results are not final. To study the issue of developing physical education programmes for learners with SEN more thoroughly, a broader, similar study should be carried

out in different regions of Ukraine. Moreover, based on the findings of this work, there is a need to develop and pilot an invariant module of the educational programme for learners with SEN, followed by the collection and processing of experimental data.

The data obtained will also be of practical use to physiotherapists in determining the content of therapeutic physical education for such children.

Conclusion

Thus, the study of the results of the assessment of learners with special educational needs (SEN) has enabled us to draw the following conclusions:

1. The findings of the study confirmed the presence of a considerable number of children with SEN who have impairments in physical development. The most common are delays in fine and gross motor skills, disorders of movement coordination and balance, postural defects, abnormalities in the structure of the feet and gait disturbances. At the same time, these issues are not dependent on the group of learning difficulties. Accordingly, the problem of deviations in the physical development of such children are worth regarding as complex, and the ways of addressing it is worth approaching through a unified, systemic strategy. A separate challenge lies in the difficulty of perceiving learning material, particularly explanations and instructions for performing motor tasks, which requires additional pedagogical support. The results obtained provide a more profound understanding of the content of physical education for learners with SEN and allow for a conceptual improvement of physical education curricula.
2. It has been proposed to include compulsory invariant content in the individual (in particular, adapted or modified) educational programmes for learners with SEN. This content should provide for the teaching and use of physical exercises aimed not only at facilitating the socialisation of such children in a community environment, but also at increasing their level of motor activity and promoting the correction of physical developmental impairments identified in conclusion 1. At the same time, it is important not only to adapt or modify the content of educational programmes, but also to carefully select teaching methods, taking into account the individual characteristics of instruction perception and the ability to perform motor tasks. The specified methodological approaches must be integrated into the individual development programme of each child with SEN.

Conflict of Interest

The authors declare that there is no conflict of interest.

References:

Bondar, T., Melnyk, D., Holub, V., & Bondar, A. (2024). Current issues of physical education for school-age children in an inclusive environment. *Scientific Journal of Mykhailo Drahomanov Ukrainian State University*, (10(183)), 60–65. (In Ukr.) [Бондар Т., Мельник Д., Голуб В., Бондар А. Актуальні проблеми фізичного виховання дітей шкільного віку в умовах інклюзивного середовища // Науковий часопис Українського державного університету імені Михайла

Драгоманова. — 2024. — Вип. 10(183). — С. 60-65.] https://doi.org/10.31392/UDU-nc.series15.2024.10(183).10

Bondar, T. S., & Melnyk, D. P. (2025). *Foundations for designing physical education in inclusive learning environments in educational institutions* [Methodical recommendations for physical education teachers]. Kremenets city council municipal institution "The Inclusive-Resource Centre". (In Ukr.). [Бондар, Т. С., Мельник, Д. П. Основи проєктування фізичного виховання в умовах інклюзивного навчання у закладах освіти [Метод. реком. для вчителів фізичної культури]. Комунальна установа Інклюзивно-ресурсний центр Кременецької міської ради, 2025.]

Borysenko, L. L. (2018). Physical culture as an inclusive environment. In *System of Education for Children with Special Educational Needs in Modern Institutions: Proceedings of the VI All-Ukrainian Scientific-Practical Conference (12 December 2018)* (pp. 23–26). Lysychansk: O. H. Chernov. (In Ukr.). [Борисенко, Л. Л. Фізична культура як інклюзивне середовище. Система надання освіти дітям з особливими освітніми потребами в умовах сучасного закладу: Зб. за матеріалами VI Всеукр. наук.-практ. конф. (12 груд. 2018 р.). Лисичанськ: ФОП Чернов О. Г. — С. 23-26.]

Development of an inclusive educational environment in general secondary education institutions. (2024). *The Centre for Analytical, Methodological, and Material-Technical Support for the Development of Educational Institutions of the Region.* (In Ukr.). [Розбудова інклюзивного освітнього середовища в закладах загальної середньої освіти // Центр аналітично-методичного та матеріально-технічного забезпечення розвитку освітніх закладів області. — 2024]. https://rozvytok-osvity.te.ua/розбудова-інклюзивного-освітнього-с/

Forostian, O. (2018a). Problems of organizing physical education lessons in an inclusive class. *Pedagogical Sciences: Theory, History, Innovative Technologies*, *8*(82). (In Ukr.). [Форостян О. (2018). Проблеми організації уроків фізичної культури в інклюзивному класі // Педагогічні науки: теорія, історія, інноваційні технології. — 2018. — № 8(82).]. https://pedscience.sspu.edu.ua/wp-content/uploads/2019/02/26.pdf

Forostian, O. I., Sheremet, B. H., Leshchii, N. P., & Maliy, V. M. (2018b). *Program of corrective-developmental work "Therapeutic Physical Culture" for grades 1–4 of special secondary education institutions for children with hearing impairments*. Kyiv: Ministry of Education and Science of Ukraine, Institute of Special Pedagogy of NAES of Ukraine. (In Ukr.). [Форостян О.І., Шеремет Б.Г., Лещій Н.П., Малій В.М. Програма з корекційно-розвиткової роботи «Лікувальна фізична культура» для 1-4 класів спеціальних закладів загальної середньої освіти для дітей з порушеннями слуху (для дітей зі зниженим слухом). Київ: Міністерство освіти і науки України, Інститут спеціальної педагогіки НАПН України, 2018.]

Horopaha, N. M. (2014). Physical education of preschoolers and younger schoolchildren in the context of inclusive education: continuity and prospects. *Renewal of Content, Forms and Methods of Teaching and Educating in Educational Institutions*, (10), 11–15. (In Ukr.). [Горопаха, Н. М. Фізичне виховання дошкільників та молодших школярів у контексті інклюзивної освіти: проблеми наступності та перспективності // Оновлення змісту, форм та методів навчання і виховання в закладах освіти. — 2014. — № 10. — С. 11–15.]. http://nbuv.gov.ua/UJRN/Ozfm_2014_10_6

Hryshchenko, O. M. (2024). Inclusive education as a condition for social adaptation of children with special needs. *Naurok*. (In Ukr.). [Грищенко, О. М. Інклюзивна освіта як одна з умов соціальної адаптації дітей з особливими потребами // На урок. — 2024.]. https://naurok.com.ua/inklyuzivna-osvita-yak-odna-z-umov-socialno-adaptaci-ditey-z-osoblivimi-potrebami-399961.html

Inclusion in Lviv region: number of children in schools. (n.d.). *Loda*. (In Ukr.). [Інклюзія на Львівщині: кількість дітей у школах // *Loda*]. https://old.loda.gov.ua/news?id=65512

On Approval of the Procedure for Organising Inclusive Learning in General Secondary Education Institutions. (2021). Resolution of the Cabinet of Ministers of Ukraine No. 957 dated September 15, 2021. (In Ukr.). [Постанова Кабінету міністрів України «Про затвердження Порядку

організації інклюзивного навчання у закладах загальної середньої освіти» від 15 вересня 2021 р. № 957.]. https://zakon.rada.gov.ua/laws/show/545-2017-%D0%BF#Text

On Approval of the Procedure for Organising Inclusive Learning in Preschool Education Institutions. (2019). Resolution of the Cabinet of Ministers of Ukraine No. 530 dated April 10, 2019. (In Ukr.). [Постанова Кабінету міністрів України «Про затвердження Порядку організації інклюзивного навчання у закладах дошкільної освіти» від 10 квітня 2019 р. № 530.]. https://zakon.rada.gov.ua/laws/show/530-2019-%D0%BF#Text

On Approval of the Regulations on the Inclusive Resource Centre. (2017). Resolution of the Cabinet of Ministers of Ukraine No. 545 dated July 12, 2017). (In Ukr.). [Постанова Кабінету міністрів України «Про затвердження Положення про інклюзивно-ресурсний центр» від 12 липня 2017 р. № 545.]. https://zakon.rada.gov.ua/laws/show/545-2017-%D0%BF#Text

On Complete General Secondary Education. (2020). Law of Ukraine No. 463-IX dated January 16, 2020). [Закон України «Про повну загальну середню освіту» від 16.01.2020 № 463-IX.]. https://zakon.rada.gov.ua/laws/show/463-20#n984

On Education. (2017). Law of Ukraine No. 2145-VIII dated September 5, 2017. (In Ukr.). [Закон України «Про освіту» від 05.09.2017 № 2145-VIII]. https://zakon.rada.gov.ua/laws/show/2145-19#Text

Poroshenko, M. A. (2019). *Inclusive education: textbook*. Kyiv: Agency "Ukraine". (In Ukr.). [Порошенко, М. А. Інклюзивна освіта: навчальний посібник. Київ: ТОВ «Агентство «Україна», 2019]

Salamanca Declaration and Framework for action on special needs education. (n.d.). *Rada*. (In Ukr.). [Саламанська декларація та рамки дій щодо освіти осіб з особливими потребами // Рада.]. https://zakon.rada.gov.ua/laws/show/995_001-94#Text

Shukatka, O., & Korzhan, O. (2022). Physical education in an inclusive environment. (In Ukr.). [Шукатка, О., Коржан, О. (2022). Фізичне виховання в інклюзивному середовищі.]. http://dspace.tnpu.edu.ua/bitstream/123456789/28515/1/Shukatka.pdf

Solovey, A., Yaroshyk, M., & Danylevych, M. (2025). Features of inclusive physical education of students with autism spectrum disorders. *Physical Culture and Sport: Scientific Perspective*, *1*(1), 371–378. (In Ukr.). [Соловей, А., Ярошик, М., Данилевич, М. Особливості інклюзивного фізичного виховання учнів з розладами аутичного спектру // Physical culture and Sport: Scientific perspective. — 2025. — Т.1 (1). — С. 371–378.]

Statistical data of the Ministry of Education and Science of Ukraine. (n.d.). Government of Ukraine. (In Ukr.). [Статистичні дані Міністерства освіти та наука України // Уряд України.]. https://mon.gov.ua/osvita-2/inklyuzivne-navchannya/statistichni-dani

Yefimenko, M. M., & Moha, M. D. (2022). Forms of inclusion in the physical development of children with special educational needs. *Actual Issues of Correctional Education (Pedagogical Sciences)*, *20*. (In Ukr.). [Єфименко, М. М., Мога, М. Д. Форми інклюзії у фізичному розвитку дітей з особливими освітніми потребами // Актуальні питання корекційної освіти (педагогічні науки). — 2022. — № 20.]. https://aqce.com.ua/vipusk-n-20-2022/efimenko-m-m-moga-m-d-formi-inkljuzii-u-fizichnomu-rozvitku-ditej-z-osoblivimi-osvitnimi-potrebami.html

Yefimenko, M. M. (2013). *Modern approaches to correctional physical education of preschoolers with motor impairments*. Vinnytsia: Nilan Ltd. (In Ukr.). [Єфименко, М. М. Сучасні підходи до корекційно спрямованого фізичного виховання дошкільників з порушеннями опорно-рухового апарату. Вінниця: Нілан ЛТД, 2013.]

Appendix

Table 1. Summary data of the assessment of children with special educational needs regarding physical development by educational difficulties (p = 0.05)

Difficulties / Physical characteristics	Impairments of movement coordination, %	Balance deficiencies, %	Difficulties in understanding tasks and instructions, %	Fine motor skill impairments, %	Gross motor skill impairments, %	Postural defects, %	Abnormalities in lower limb structure, %	Gait abnormalities, %	Weak immunity, %
Total children examined (n=103)	52,4	51,5	44,7	35,9	46,6	63,1	56,3	31,1	15,5
Of these:									
Intellectual difficulties (n=21)	71,4	66,7	66,7	47,6	57,1	76,2	66,7	38,1	9,5
Physical difficulties (n=4)	75	75	25	50	75	75	75	75	50
Functional difficulties (n=18)	50	44,4	55,6	22,2	33,3	61,1	50	33,3	16,7
Learning difficulties (n=34)	38,2	38,2	11,8	29,4	35,3	61,8	55,9	17,6	20,5
Socio-adaptive difficulties (n=26)	53,8	42,3	65,4	42,3	57,7	53,8	50	34,9	7,7

Table 2. Correlation Matrix of Physical Development Anomalies in Students with Special Educational Needs

		1	2	3	4	5	6	7
1	Movement coordination disorders							
2	Balance impairments	0,99910						
3	Difficulties in performing tasks and following instructions	0,96693	0,96727					
4	Fine motor skill impairments	0,99504	0,99771	0,95627				
5	Gross motor skill impairments	0,99523	0,99844	0,96458	0,99880			
6	Postural disorders	0,99144	0,99006	0,92866	0,98803	0,98522		
7	Lower limb structural abnormalities	0,99106	0,99058	0,92703	0,98992	0,98703	0,99969	
8	Gait disorders	0,99472	0,99452	0,97846	0,98675	0,99153	0,97774	0,97737

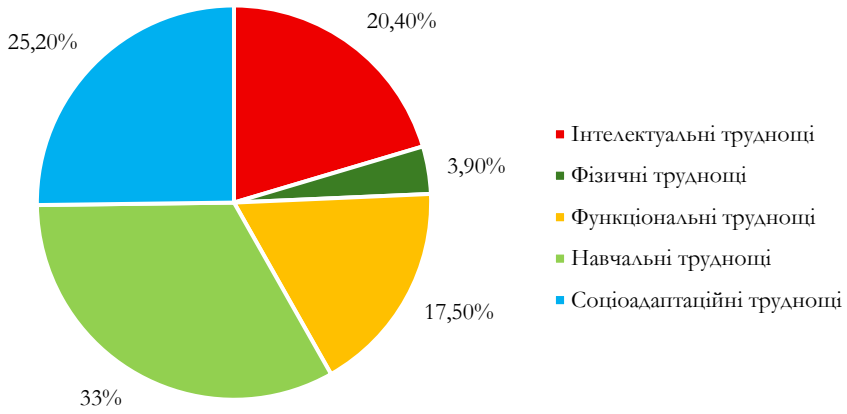

Figure 1. Number of children with special educational needs by groups of learning difficulties (In Ukr.)

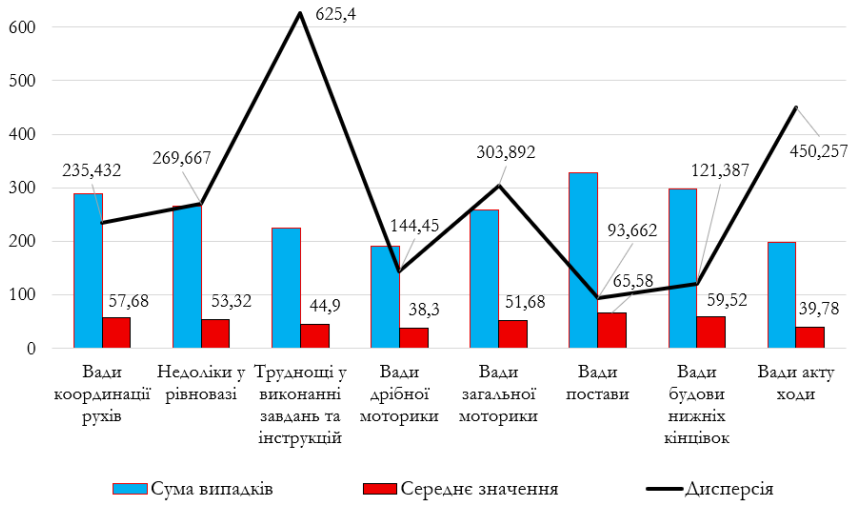

Figure 2. Data on the standard deviation from the mean values according to educational difficulties (In Ukr.)

Ivan Riabko [a][12], *Mykyta Nechaiev* [b][13]

Functional MRI Training for Biomedical Physics and Engineering Students: Methodological Approach to Acquisition, Processing and Visualization [2]

Abstract: Functional magnetic resonance imaging (fMRI) represents a cornerstone technique for studying brain activity and connectivity, yet its application in biomedical engineering education remains limited. The study's object was the process of teaching and learning fMRI methodologies within biomedical physics and engineering education. The study's subject was the methodological framework and practical module integrating acquisition, preprocessing, modelling, and visualisation of fMRI data for undergraduate training. The study aimed to design, implement, and evaluate a hands-on educational module that bridges the gap between theoretical knowledge and practical competence in fMRI workflows for biomedical students. Based on a teaching internship, a practical module was designed and implemented for undergraduate students of biomedical physics, engineering, and informatics that covered the complete fMRI workflow. The module combined an on-site visit to a radiology centre, participation in a scanning session with a simple block-design task, and a hands-on laboratory focused on preprocessing, modeling, and visualization using open-source tools. A preconfigured virtual environment with FSL and standardized data conversion via BIDS/BIDScoin enabled a reproducible pipeline from DICOM to NIfTI/BIDS and downstream modeling in FEAT. Students practiced brain extraction, spatial normalization, model specification for block designs, and interpretation of thresholded activation maps in FSLeyes. Educational outcomes included improved understanding of neuroimaging pipelines, stronger operational skills with widely used software, and higher motivation for interdisciplinary research. This work proposes a methodological framework for integrating fMRI-based training into biomedical curricula and bridging technical education with modern neuroimaging applications.

Keywords: functional MRI, biomedical physics, neuroimaging, preprocessing, visualization, education.

Abbreviations:

BET is brain extraction,

BIDS is Brain Imaging Data Structure,

BOLD is blood-oxygen-level dependent,

fMRI is functional magnetic resonance imaging,

FSL is fMRIB Software Library,

GLM is general linear model,

QC is quality control,

ROI is Region of Interest,

TFCE is threshold-free cluster enhancement.

[a] Master of Science in Biomedical Physics and Informatics, Engineer – Radiophysicist, Department of Radiation Safety, Faculty of Radiophysics, Electronics and Computer Systems, Taras Shevchenko National University of Kyiv, National Children's Specialized Hospital "OHMATDYT". Kyiv, Ukraine.

[b] Head of the Center, Radiology Centre, Department of Radiology and Radiation Medicine, Bogomolets National Medical University, National Children's Specialized Hospital "OHMATDYT". Kyiv, Ukraine.

Introduction

fMRI has become one of the most important noninvasive techniques for studying the human brain. Based on the BOLD signal, it provides a window into functional activity and network connectivity and is widely applied in neuroscience, neurology, and cognitive research (*Poldrack et al., 2011*; *Logothetis et al., 2001*). The growing role of neuroimaging in clinical practice and the biomedical sciences highlights the need for students in biomedical physics, engineering, and informatics to acquire practical knowledge of this methodology.

Traditional curricula often focus primarily on theoretical aspects of medical imaging and physics but provide limited exposure to real-world data acquisition and analysis pipelines. This gap between theory and practice is especially evident in interdisciplinary environments where biomedical engineers and physicists are expected to operate confidently across acquisition, preprocessing, modeling, and visualization stages. Addressing this gap requires integrating methodological training based on authentic neuroimaging workflows.

As part of a teaching internship, a practical module was created to introduce undergraduate students to the complete fMRI workflow. The module comprised four components: an on-site visit to a radiology centre (equipment orientation and safety briefing), participation in an fMRI scanning session with a simple block-design paradigm, an online laboratory dedicated to preprocessing and analysis in a preconfigured environment using FSL with standardized data conversion via BIDS/BIDScoin, and a closing discussion focused on reflection and recommended learning pathways.

The study's object was the process of teaching and learning fMRI methodologies within biomedical physics and engineering education.

The study's subject was the methodological framework and practical module integrating acquisition, preprocessing, modelling, and visualisation of fMRI data for undergraduate training.

The study aimed to design, implement, and evaluate a hands-on educational module that bridges the gap between theoretical knowledge and practical competence in fMRI workflows for biomedical students.

Based on the purpose of the study, the following tasks were solved:

- analyse the limitations of traditional curricula in biomedical physics and engineering regarding neuroimaging training;
- develop a structured teaching module that incorporates authentic fMRI workflows, including acquisition, preprocessing, modelling, and visualisation stages;
- implement the module in practice through radiology centre visits, fMRI scanning sessions, virtual laboratory training, and reflective discussion;
- assess the educational outcomes in terms of students' technical competence, ability to critically interpret activation maps, and readiness for interdisciplinary collaboration;
- outline recommendations for future improvements in scalability, reproducibility, and integration of advanced statistical approaches and software environments.

The following scientific methods are used to achieve the goals and solve the study's tasks:

1. Literature analysis of neuroimaging methodologies and educational practices;
2. Pedagogical design of a practical fMRI training module;
3. Experimental implementation through an internship-based teaching sequence;

4. Practical demonstration of fMRI data acquisition using a block-design paradigm;
5. Computational analysis with FSL tools (FEAT, BET, FLIRT/FNIRT, FSLeyes) in a preconfigured virtual environment;
6. Reflection and qualitative assessment of students' learning outcomes and skill development.

The primary objective of this methodological initiative was to move beyond theoretical familiarity and cultivate hands-on skills in data organization, preprocessing, general linear modeling, and visualization of activation maps. By engaging students in practical analysis of functional imaging data within a reproducible software ecosystem, the approach aimed to improve technical competence, encourage interdisciplinary collaboration, and increase motivation for further research.

Thus, this article describes the methodological framework and educational outcomes of teaching fMRI to biomedical physics and engineering students, emphasizing its role in bridging technical education with modern neuroimaging applications.

Methods

The research applied a comprehensive combination of general scientific and special methodological approaches to ensure the validity and reproducibility of the proposed educational framework for fMRI training in biomedical physics and engineering. The general scientific methods included systemic, analytical, comparative, and experimental approaches aimed at identifying the gap between theoretical preparation and practical skills in neuroimaging education. The study was grounded in the principles of scientific rationality, reproducibility, and evidence-based pedagogy. The systemic approach made it possible to consider the fMRI educational module as a complex didactic system integrating theoretical instruction, clinical practice, data processing, and reflection. Analytical and comparative methods were used to review existing neuroimaging training paradigms and determine their correspondence to international educational standards in biomedical engineering. Experimental implementation served as the empirical basis for verifying the efficiency of the developed methodological sequence.

The research followed a mixed-method design that integrated elements of pedagogical experiment and applied technological testing. A teaching internship environment provided the experimental platform for implementing the proposed fMRI training module. The educational process was organized in four sequential stages—introductory theoretical preparation, on-site radiology practice, virtual laboratory for data preprocessing and analysis, and final reflection—allowing the authors to trace students' learning progress dynamically. Quantitative data were collected from practical tasks, while qualitative feedback was derived from students' reflective reports and guided discussions. This triangulation of data ensured comprehensive assessment of learning outcomes and methodological consistency.

The pedagogical experiment involved undergraduate students in biomedical physics, engineering, and informatics. Prior to practical sessions, participants received theoretical instruction on fMRI principles, safety procedures, and acquisition protocols. During on-site practice, they participated in a functional scanning session using a left-hand finger-tapping paradigm on a 1.5 T MRI system. This stage simulated real-world neuroimaging procedures, fostering comprehension of scanner operation, timing logic, and task compliance (*Poldrack et al.,*

2011). The imaging protocol included BOLD fMRI and 3D T1-weighted MPRAGE sequences to ensure sufficient spatial resolution for subsequent normalization and modeling (*Logothetis et al., 2001*).

Specialized scientific methods were employed to provide technical and analytical depth to the pedagogical framework. Computational methods were central to the module, involving standardized data conversion from DICOM to NIfTI/BIDS using BIDScoin (*Gorgolewski et al., 2016*; *Brain Imaging Data Structure, 2023*). Preprocessing and analysis were conducted in the FSL environment within a preconfigured lin4neuro virtual machine (Jenkinson et al., 2012). The pipeline incorporated BET, motion correction, spatial smoothing, and registration to both individual anatomical and MNI152 standard spaces via FLIRT and FNIRT. Statistical modeling was implemented through the GLM using FEAT, enabling the detection of task-related activations (*Friston et al., 1994*). Visualization and interpretation were performed in FSLeyes, where thresholded activation maps were evaluated for alignment accuracy and anatomical validity.

In addition to technical methods, the study applied pedagogical diagnostics and reflective analysis. Students' performance was evaluated through QC reports, annotated activation maps, and written reflections, which provided insight into their understanding of preprocessing logic, statistical modeling, and the interpretation of activation patterns. Reflection served both as a qualitative research method and a pedagogical instrument, supporting metacognitive development. To strengthen methodological reliability, reproducibility was ensured by maintaining identical software environments, datasets, and task structures across participants.

Thus, the research combined pedagogical experimentation with applied neuroimaging methodology to establish a reproducible model of fMRI education. The integration of general scientific approaches with domain-specific computational tools enabled a transition from theoretical familiarity to hands-on expertise, providing an empirical foundation for enhancing the quality of biomedical engineering curricula and aligning them with contemporary neuroimaging standards.

Literature Review

fMRI has evolved into one of the most influential tools in modern neuroscience and biomedical research, enabling non-invasive exploration of brain activity through BOLD contrast (*Logothetis et al., 2001*). Since its introduction in the 1990s, fMRI has become indispensable for investigating cognitive, sensory, and motor processes, and it continues to serve as the methodological foundation for translational studies linking neural mechanisms with behaviour and pathology (*Poldrack et al., 2011*). However, despite its scientific importance, educational integration of fMRI remains underdeveloped in biomedical engineering curricula, where emphasis traditionally lies on physics and instrumentation rather than on full data-processing workflows. Bridging this pedagogical gap requires an understanding of methodological advances in neuroimaging and their didactic adaptation.

The theoretical basis of fMRI data analysis rests upon the GLM, which provides a statistical framework for identifying task-related changes in BOLD signal (*Friston et al., 1994*). Over time, refinements of the GLM and its derivatives—such as random-effects models and cluster-based inference—have improved the accuracy and reproducibility of neuroimaging findings. The

introduction of TFCE further mitigated problems of arbitrary thresholding and spatial smoothing, ensuring more reliable localization of activations (*Smith & Nichols, 2009*). Mastery of these statistical approaches is essential for students of biomedical physics and engineering, as it builds a bridge between theoretical modelling and practical interpretation of brain activity.

An equally important methodological shift has been the standardization of data organization through the BIDS, which formalized the description and storage of neuroimaging datasets (*Gorgolewski et al., 2016*). BIDS promotes transparency, reproducibility, and interoperability, qualities that are increasingly demanded by the open-science movement (*Brain Imaging Data Structure, 2023*). The accompanying BIDScoin toolkit simplifies data conversion from DICOM to BIDS format, reducing the likelihood of errors and enabling cross-platform analyses. Incorporating such standards into educational settings familiarizes students with the workflows expected in contemporary neuroimaging laboratories.

The choice of software tools also plays a crucial pedagogical role. Among the most widely used packages, the FSL offers an integrated suite for preprocessing, statistical analysis, and visualization (*Jenkinson et al., 2012*). Its modules—BET for brain extraction, FLIRT/FNIRT for registration, and FEAT for modelling—provide a complete ecosystem for practical training. FSL's open-source nature aligns with the didactic goals of reproducibility and accessibility, allowing students to gain hands-on experience without reliance on proprietary platforms. Complementary toolkits such as AFNI (*Cox, 1996*) extend analytical possibilities and encourage comparative understanding of different computational ecosystems.

The growing emphasis on reproducibility in neuroimaging research has fostered the development of preconfigured virtual environments such as lin4neuro, which encapsulate all necessary dependencies for running FSL and related tools. These environments minimize configuration variability and make it feasible for students to replicate complex workflows on their personal computers. Such reproducible pipelines have transformed the pedagogical landscape of biomedical physics education by enabling scalable and ethically safe training with anonymized or simulated datasets.

Educationally, the integration of neuroimaging practice within biomedical curricula reflects a broader trend towards interdisciplinary learning. The intersection of physics, engineering, and neuroscience demands not only technical competence but also interpretive skills in data visualization and critical reasoning (*Poldrack et al., 2011*). Visualization tools like FSLeyes have become vital in fostering spatial understanding of brain function, linking statistical maps to anatomical landmarks. Moreover, structured training in reporting standards and figure preparation prepares students for participation in scientific communication and publication.

Overall, the literature converges on the necessity of combining methodological rigor with pedagogical innovation. Contemporary research underscores that teaching fMRI should go beyond theoretical instruction by involving authentic data, standardized workflows, and reflection-based learning. The adoption of open-source tools, standardized formats such as BIDS, and reproducible virtual environments aligns education with the best practices of modern neuroimaging. Consequently, integrating such frameworks into biomedical engineering programs not only enhances technical proficiency but also cultivates a research culture grounded in transparency, collaboration, and critical inquiry.

Results

Organization of the training and course design

The module was organized as a four-step sequence that connected theoretical preparation with authentic practice: a visit to the radiology centre with equipment orientation and safety briefing; participation in an fMRI session using a simple block-design task; a hands-on laboratory focused on preprocessing and analysis in a preconfigured environment; and a closing discussion with reflection and recommended learning pathways. To ensure reproducibility and transparent data handling, the workflow incorporated standardized conversion from DICOM to NIfTI/BIDS using BIDS/BIDScoin (*Gorgolewski et al., 2016*; *Brain…, 2023*; *BIDScoin…, n.d.*). A preconfigured virtual machine (lin4neuro) provided a unified software stack with FSL and auxiliary tools, enabling students to work in a consistent environment across different computers (*Jenkinson et al., 2012*).

Thus, the course design intentionally linked conceptual preparation with authentic data collection and standardized analysis. The sequential flow (centre → scanner → lab → reflection) reduced cognitive load, improved reproducibility through BIDS, and provided a stable environment for practice, allowing students to progress from theory to executable workflows and to consolidate skills through structured reflection. A structured overview of the module content and its components is presented in the Appendix (*Table 1*).

fMRI acquisition process and student involvement

Students were introduced to clinical-like procedures at the radiology centre using a 1.5 T system. After a safety briefing, participants completed a block-design paradigm in the scanner consisting of left-hand finger tapping. The paradigm followed a 40 s rest / 40 s task timing repeated three times (total 240 s). The imaging protocol included diffusion, BOLD fMRI, and 3D T1-weighted MPRAGE (isotropic) for normalization and localization. The session emphasized task compliance, scanner etiquette, and understanding how sequence choice and timing affect downstream modeling (*Poldrack et al., 2011*).

Thus, direct participation in acquisition familiarized students with equipment workflow, safety, task execution, and timing logic, creating a concrete foundation for subsequent preprocessing and statistical modeling. Examples of the resulting activation patterns for the finger tapping paradigm are shown in the Appendix (*Figure 1*).

Data preprocessing and analysis with software tools (FSL, lin4neuro)

The computational workflow was carried out in FSL within a preconfigured lin4neuro virtual machine, ensuring a stable and reproducible environment. Raw DICOM data were converted to NIfTI/BIDS using BIDS/BIDScoin with validation prior to analysis (*Gorgolewski et al., 2016*; *Brain…, 2023*; *BIDScoin…, n.d.*). In FSL/FEAT, students followed a step-by-step preprocessing pipeline that included BET, spatial smoothing, and registration first to each participant's T1 anatomy via FLIRT and subsequently to the MNI152 standard space, with optional nonlinear refinement using FNIRT.

A block-design general linear model was implemented to capture alternating periods of task and rest, and FEAT's autogenerated HTML reports were examined for quality control.

Visualization was performed in FSLeyes, where students inspected activation maps in both 2D and 3D views, compared them against anatomical references, and overlaid standard atlases to better interpret the spatial distribution of activations.

Thus, a BIDS-organized workflow combined with a preconfigured VM enabled training that progressed from data conversion through preprocessing, normalization to MNI152, model specification, and visualization. Students not only practiced operational use of FSL tools (FEAT, BET, FLIRT/FNIRT, and FSLeyes), but also developed an understanding of how preprocessing and design choices influence statistical outcomes (*Friston et al., 1994*; *Poldrack et al., 2011*).

Visualization of brain activation and interpretation

Using FSLeyes, students overlaid thresholded statistical maps onto each participant's T1-weighted anatomy, adjusted intensity ranges and transparency, and interactively examined coordinates, cluster sizes, and spatial extent. This hands-on practice emphasized not only visualization but also critical inspection of potential artifacts and alignment accuracy.

Interpretation exercises focused on relating model regressors to canonical task-related activations—e.g., contralateral sensorimotor cortex during finger tapping—while stressing the limitations of single-subject inference and the need for replication across sessions or groups.

The session concluded with structured guidance on reporting standards and figure preparation for appendices. In this way, visualization and interpretation training consolidated students' ability to critically read statistical parametric maps, articulate anatomy-informed conclusions aligned with the experimental design, and recognize the bridge between data acquisition, modeling, and scientific communication (*Jenkinson et al., 2012*; *Poldrack et al., 2011*; *Figure 1A–C*).

Discussion

The core problem addressed is the persistent gap between theoretical coverage of neuroimaging and students' hands-on competence with acquisition, preprocessing, and modeling pipelines. Constraints include limited scanner access, small cohorts, and reliance on single-subject analyses, which restrict generalizability and formal evaluation of learning outcomes. Reproducibility also remains sensitive to environment configuration and data standardization, even with BIDS and a preconfigured VM (*Brain…, 2023*; *BIDScoin…, n.d.*).

Future work should implement a structured evaluation framework (pre/post testing, rubric-based map interpretation, and practical checklists) and compare delivery modes (local VM, containerized setups, or cloud workspaces) and alternative software ecosystems such as AFNI (*Cox, 1996*). Extending tasks beyond simple block designs and introducing group-level statistics would deepen methodological understanding. Incorporating open datasets, simulated fMRI for ethics and practice, and interprofessional collaboration with clinicians could further enhance realism, scalability, and impact of the training. Additionally, cluster-wise inference options such as threshold-free cluster enhancement (TFCE) may be considered in future iterations to mitigate threshold dependence (*Smith & Nichols, 2009*).

Conclusion

The implemented preprocessing and analysis pipeline enabled students to acquire operational competence with core fMRI workflows, including brain extraction, spatial normalization, and thresholded statistical mapping. Particular emphasis was placed on quality control using FSLeyes, where participants critically evaluated alignment accuracy, potential artifacts, and anatomical localization of task-related activations.

Through interpretation exercises, students successfully related regressors to canonical activation patterns, most notably contralateral sensorimotor cortex responses during finger tapping. These exercises underscored both the value of single-subject fMRI for functional localization and its limitations for broader inference, highlighting the importance of replication across sessions and subjects.

Finally, the training consolidated students' ability to connect methodological rigor with scientific communication by adhering to reporting standards and figure preparation guidelines. While limited by small cohorts and restricted scanner time, the module provides a reproducible baseline for expanding to group-level statistics, diversified paradigms, and alternative delivery modes (e.g., containerized or cloud-based environments).

In sum, the internship-based module was not only created but also tested in practice, providing a scalable blueprint for integrating fMRI-based training into biomedical curricula and bridging technical education with contemporary neuroimaging practice.

Conflict of Interest

The authors declare that there is no conflict of interest.

References:

BIDScoin Workflow Documentation. (n.d.). *Bidscoin*. https://bidscoin.readthedocs.io/en/latest/workflow.html

Brain Imaging Data Structure (BIDS) Specification. (2023). *Neuroimaging*. https://bids.neuroimaging.io

Cox, R. W. (1996). AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical Research*, *29*(3), 162–173. PMID: 8812068. https://doi.org/10.1006/cbmr.1996.0014

FMRIB Software Library (FSL) Wiki. (2012). *FSL*. https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/

Friston, K. J., Holmes, A. P., Worsley, K. J., Poline, J.-B., Frith, C. D., Frackowiak, R. S. J. (1994). Statistical parametric maps in functional imaging: a general linear approach. *Human Brain Mapping*, *2*(4), 189–210. https://doi.org/10.1002/hbm.460020402

Gorgolewski, K. J., Auer, T., Calhoun, V. D., Craddock, R. C., Das, S., Duff, E. P., et al. (2016). The brain imaging data structure, a format for organizing and describing outputs of neuroimaging experiments. *Scientific Data*, *3*, 160044. https://doi.org/10.1038/sdata.2016.44

Jenkinson, M., Beckmann, C. F., Behrens, T. E. J., Woolrich, M. W., & Smith, S. M. (2012). FSL. *NeuroImage*, *62*(2), 782–790. PMID: 21979382. https://doi.org/10.1016/j.neuroimage.2011.09.015

Logothetis, N. K., Pauls, J., Augath, M., Trinath, T., & Oeltermann, A. (2001). Neurophysiological investigation of the basis of the fMRI signal. *Nature*, *412*(6843), 150–157. PMID: 11449264. https://doi.org/10.1038/35084005

Poldrack, R. A., Mumford, J. A., & Nichols, T. E. (2011). *Handbook of functional MRI Data analysis*. Cambridge University Press.

Smith, S. M., & Nichols, T. E. (2009). Threshold-free cluster enhancement: addressing problems of smoothing, threshold dependence and localisation in cluster inference. *NeuroImage*, *44*(1), 83–98. PMID: 18501637. https://doi.org/10.1016/j.neuroimage.2008.03.061

Appendix

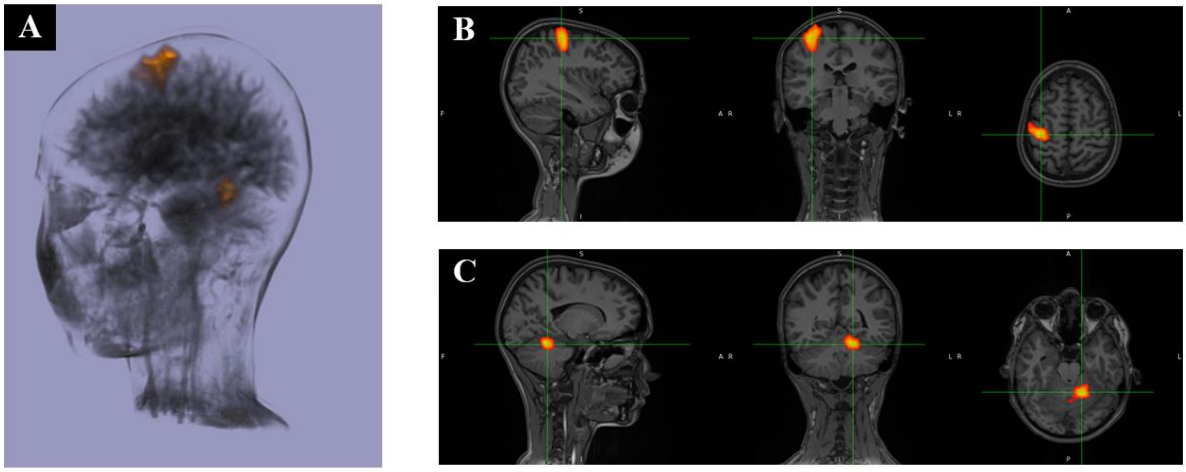

Figure 1. Left-hand finger tapping ($Z \geq 3.1$). (A) 3D volume rendering of thresholded activation; (B) orthogonal views centred on the hand knob in the right precentral gyrus (M1), showing contralateral sensorimotor activation; (C) close-up of ipsilateral activation in the superior left cerebellar hemisphere near the paravermian zone (lobules V/VI), consistent with the sensorimotor representation.

Table 1. Content and structure of the fMRI educational course

Module / Component	Objectives (Learning Outcomes)	Duration	Tools / Materials	Assessment / Output
Lecture Session	fMRI principles; clinical applications	60–75 min	Slides, key readings	Q&A, attendance
Introduction & Safety	fMRI basics; safety briefing; scanner workflow	45–60 min	Slides, MRI safety forms	Attendance, Q&A
fMRI Acquisition	Execute tasks (left-hand tapping, rest)	20–30 min/run	1.5T system, BOLD EPI sequences	Log of runs, compliance notes
Data Processing	DICOM→BIDS conversion, preprocessing, FEAT pipeline	2–3 h	BIDScoin, FSL, lin4neuro VM	QC report, GLM outputs
Data Analysis	Statistical modelling, threshold maps, ROI inspection	2 h	FSLeyes, standard atlases	Annotated figures, short essay
Interpretation & Wrap-up	Group discussion; clinical implications; next steps	45–60 min	Slides, sample cases	Written reflection, feedback

Olha O. Mazurenko [a][14]

Emotionally Adaptive UX Interfaces: A Scenario-Based Framework for Real-Time Personalization [10]

Abstract: The increasing complexity of user needs and digital contexts necessitates the development of adaptive user interfaces capable of emotional responsiveness. Traditional emotional personalization methods, reliant on biometric data, often prove costly, intrusive, or impractical for early prototypes and large-scale deployments, raising privacy concerns. This paper addresses these limitations by introducing a novel conceptual scenario-based behavioral framework for emotionally adaptive web UX. The object of the study is to explore how user interfaces can dynamically adjust to a user's affective state using only observable behavioral indicators, without physiological sensors. The study aims to demonstrate that cues like navigation style, input pacing, or reaction latency can inform UX modifications aligning with emotional states, offering a scalable and ethically sustainable alternative or complement to biometric solutions. The methodology involved developing three synthetic user personas (stressed, bored, focused) based on Plutchik's Wheel of Emotions and validated behavioral attributes. Interface mockups were designed in Figma, focusing on adaptive UX fragments. A structured heuristic evaluation, using a 5-point Likert scale and seven key metrics (e.g., perceived emotional fit, cognitive effort, mental model resonance) aligned with ISO 9241–210:2019 and ISO/IEC 25010:2023, assessed the framework. This work integrates insights from key researchers: Zeng et al. and Chen & Li on emotional congruence; Nielsen, Sarodnick & Brau on heuristic evaluation; Huang & Singh on emotional fit; Gentner & Stevens on mental models; and Liu & Wei and Khan & Shukla on emotion-aware computing. Results show that Hypothesis H1, affirming significant emotional alignment from scenario-based adaptation without real-time sensing, was validated. The stressed (4.6 emotional fit) and focused (4.7 mental model resonance) personas showed high alignment. Hypothesis H2, concerning behavioral adaptation's sufficiency in low-tech contexts and its complementary role in high-fidelity designs, was also supported. Critically, the boredom scenario (low engagement 2.9) highlighted that overstimulation without guidance can disrupt mental models, suggesting the need for refined hybrid adaptation logic. The findings confirm emotional responsiveness can be approximated via behavioral interface design, with hybrid systems offering dynamic fine-tuning. This framework introduces a vital "hybrid potential" for both substituting biometrics in constrained environments and augmenting them in high-stakes systems.

Keywords: emotion-aware UX, adaptive interface, personalization, user modeling, affective computing, neural design logic, behavioral adaptation, scenario-based design.

Abbreviations:

AI is Artificial Intelligence,

HCI is Human-Computer Interaction,

UAI is adaptive user interface,

UX is User Experience.

Introduction

The escalating complexity of user needs and digital contexts necessitates the development of adaptive user interfaces capable of emotional responsiveness. Current emotional

[a] Candidate of Engineering Science (Ph.D.), Senior Lecturer, Department of Information Technology, Artificial Intelligence and Cybersecurity, Faculty of Automation and Computer Systems, National University of Food Technologies. Ukraine, Kyiv.

personalization often relies on costly, intrusive biometric data, limiting its practical and ethical application.

This paper introduces a novel conceptual scenario-based behavioral framework for emotionally adaptive web UX, utilizing observable indicators for simulated real-time adjustments.

The object of the study is to explore how user interfaces can dynamically adapt to a user's affective state through non-invasive behavioral cues like navigation style, input pacing, or reaction latency.

The primary aim is to demonstrate that such cues can effectively inform UX modifications, offering a scalable and ethically sustainable alternative or complement to biometric solutions.

The methodology involves developing three synthetic user personas (stressed, bored, focused), meticulously modeled using Plutchik's Wheel of Emotions and validated behavioral attributes. Interface adaptations are then evaluated through a structured heuristic assessment, employing key metrics aligned with ISO 9241–210:2019 and ISO/IEC 25010:2023. This work builds upon foundational research by Zeng et al., Chen & Li, Nielsen, Sarodnick & Brau, Liu & Wei, Khan & Shukla, Huang & Singh, and Gentner & Stevens. The results are intended for UX designers, interface engineers, and HCI researchers seeking practical and ethical personalization strategies.

Methods

1. User Scenarios and Emotional States

Three synthetic user personas were developed to simulate distinct affective contexts. Each persona was modeled using Plutchik's Wheel of Emotions, validated with UX-related behavioral attributes drawn from prior studies (*Matsuda et al., 2018*; *Dalvand & Kazemifard, 2013*):

- Persona A (*Figure 1*): A time-pressured user experiencing stress. Mental model: expects rapid task resolution with minimal distractions.
- Persona B (*Figure 2*): A disengaged user experiencing boredom. Mental model: anticipates interactive feedback, novelty, and agency in task progression.
- Persona C (*Figure 3*): A focused user with high need for continuity and minimal distraction. Mental model: expects high predictability, clear task progression, and low interface noise.

Interface mockups were created in Figma and included UX fragments—specific elements affected by emotional adaptation (e.g., login forms, confirmation modals, navigation sidebars). For each persona, the before and after states of selected fragments were redesigned to align with the user's predicted emotional and cognitive state, based on inferred mental models.

For instance, the mental model of Persona A prioritizes efficiency and clarity; therefore, checkout forms were adapted to include only essential fields, no branching logic, and passive visual cues. Persona B's mental model is exploratory and engagement-seeking, hence the addition of tooltips and visual feedback to maintain curiosity. Persona C seeks uninterrupted execution and consistency, leading to simplification of system prompts and use of progressive disclosure. Thus, these persona-specific adaptations highlight how behavioral indicators, when mapped to underlying emotional states and mental models, can guide targeted UX modifications even without direct physiological input, establishing a foundational proof-of-concept for the proposed framework's design principles.

2. Evaluation Approach

A structured heuristic evaluation was performed using a 5-point Likert scale (1 = very poor, 5 = excellent). Seven evaluation metrics were selected:

1. Perceived emotional fit
2. Interaction fluency
3. Cognitive effort
4. Disruption recovery
5. Engagement stimulation
6. Affective friction points
7. Resonance with mental model

Here, the inclusion of "resonance with mental model" allows direct tracing of interface logic to user expectations (*Figure 4*). This improves the accuracy of emotional alignment and surfaces areas where system design contradicts user assumptions. Thus, the comprehensive set of evaluation metrics, including novel ones like "resonance with mental model", provides a robust framework for assessing the effectiveness of emotionally adaptive interfaces, ensuring that both functional and affective aspects of user experience are thoroughly evaluated.

Literature Review

Research on emotionally UAIs has evolved from early models of affective computing toward integrated, user-centred frameworks that fuse emotional recognition, context awareness, and dynamic adaptation. The foundations of this field were laid by Tao and Tan (*2005*), who conceptualised affective computing as the ability of systems to recognise, interpret, and simulate human emotions. This early theoretical groundwork was expanded by Duric et al. (*2002*), who proposed combining perceptual and cognitive modeling to improve the intelligence and adaptability of human-computer interactions. Together, these works provided the conceptual basis for adaptive UX systems capable of understanding user emotion and behavior in real time.

Calvo and D'Mello (*2010*) advanced this field through an interdisciplinary review of affect detection models, integrating psychological, physiological, and computational perspectives. Their taxonomy of affective models identified multimodal recognition—such as facial expressions, voice, and physiological signals—as essential for reliable emotion detection in user interfaces. This comprehensive approach paved the way for practical adaptive systems capable of personalising interfaces based on affective cues. Dalvand and Kazemifard (*2013*) further demonstrated the feasibility of emotional adaptation by designing an adaptive user interface responsive to users' emotional states, showing that real-time feedback can significantly enhance interaction satisfaction.

In parallel, the conceptual understanding of UX evolved. Bargas-Avila and Hornbæk (*2021*) proposed a unified model of UX that combines emotional, cognitive, and behavioural dimensions. This model recognised emotion as a central determinant of UX quality, emphasising the need for design approaches that dynamically adjust to users' affective states. Similarly, Chen and Li (*2021*), in their systematic review, reinforced the view that emotion is not a peripheral factor but a core driver of UX, shaping user engagement, satisfaction, and decision-making processes. Their findings underline the need for adaptive systems that can interpret and respond to user emotions holistically.

Recent studies have focused on formalising the mechanisms through which adaptation occurs. Alipour, Céret, and Dupuy-Chessa (*2023*) proposed a temporal-emotion framework for user interface adaptation, emphasising that emotional states evolve dynamically and require temporally sensitive adaptation strategies. Their work highlights the importance of designing interfaces capable of recognising emotional trajectories rather than static states. In similar spirit, Stephanidis et al. (*2021*) developed a comprehensive framework for UX evaluation in intelligent environments, positioning emotional adaptation within the broader context of multimodal interaction and ambient intelligence. This holistic evaluation approach supports iterative design processes that balance user satisfaction, efficiency, and affective resonance.

Empirical research has further validated these frameworks. Matsuda, Yoshida, and Oka (*2018*) demonstrated through their EmoTour system that multimodal behavioural cues—such as gaze direction, facial expression, and voice tone—can be effectively used to infer user emotions and satisfaction. Schuller et al. (*2018*) contributed by analysing large-scale affective computing challenges, identifying computational paralinguistics as a key enabler for robust emotion recognition across real-world environments. More recently, Sun and Jiang (*2025*) used eye-tracking to link gaze behaviour with emotional experience, revealing that subtle visual attention patterns can predict affective responses to interface design elements. Such findings reinforce the necessity of integrating physiological and behavioral indicators into adaptive UX systems.

Parallel advancements in conversational and AI-driven systems have expanded the scope of emotional adaptation. Mahmud et al. (*2025*) reviewed UX evaluation in conversational recommender systems, comparing classical approaches with large language model (LLM)-based frameworks. Their study demonstrated that emotional adaptivity plays a crucial role in improving user trust and engagement, particularly in AI-mediated interactions. These insights connect affective computing with the emerging paradigm of emotionally aware AI, where the interface itself becomes a participant in the user's emotional context.

Collectively, the literature reveals a clear progression from theoretical conceptualisations of affective computing to data-driven, context-sensitive, and temporally adaptive UX systems. Emotionally adaptive interfaces are now recognised as essential to personalisation, contributing to more natural, empathic, and satisfying user experiences. Future frameworks, as the reviewed studies suggest, must integrate multimodal sensing, real-time analytics, and continuous emotional feedback loops to achieve seamless interaction that respects both the cognitive and affective dimensions of human behaviour (*Alipour et al., 2023*; *Stephanidis et al., 2021*).

Results

Expert ratings for each persona-interface pair are summarized in the Appendix (*Table 1*). Key findings include:

- Persona A (stress scenario): The adapted interface significantly aligned with the user's stress-avoidant mental model—minimal interactions, limited color saturation, and sequential flow. High emotional fit (4.6) and low friction (1.2) were observed. Experts emphasized rapid task completion and reduction of intrusive elements. This supports H1, affirming that simulated behavioral changes can evoke emotional congruence. Thus, the successful emotional alignment achieved for Persona A strongly supports Hypothesis H1,

demonstrating that simulated behavioral changes, carefully designed to match a user's mental model, can indeed evoke significant emotional congruence and improve user comfort in a stress-avoidant context.

- Persona B (boredom scenario): Despite efforts to stimulate interaction via color and micro-feedback, the adapted interface received lower scores in engagement (2.9) and resonance (3.0). Experts noted mismatch between intended emotional lift and actual user clarity. This highlights a key insight: overstimulation without guidance can break the user's mental model, leading to affective friction. The data supports refinement of hybrid adaptation logic—where behavioral cues must balance novelty with narrative coherence. Thus, the findings for Persona B underscore the complexity of adapting to boredom; while behavioral cues offer potential for stimulation, they must be carefully balanced with narrative coherence to avoid overwhelming the user and disrupting their mental model, suggesting a need for more nuanced, possibly hybrid, adaptation strategies.
- Persona C (focus scenario): The adapted UI matched user expectations for minimal distraction, strong task continuity, and predictability. Ratings were highest across all metrics (emotional fit: 4.4; interaction fluency: 4.6; mental model resonance: 4.7). Thus, the exceptional performance for Persona C validates the effectiveness of minimalist and predictable behavioral adaptations for focused users, strongly reinforcing the role of precise cognitive-affective alignment in optimizing user experience for uninterrupted concentration and task completion. These results reinforce the role of cognitive-affective alignment in focused experiences and validate scenario-based predictions.

Critically, results across all personas demonstrate that emotional responsiveness can be approximated through behavioral interface design even without live sensing. However, in complex scenarios (e.g., boredom), hybrid systems may be needed to dynamically fine-tune UI responses. This hybrid potential is particularly relevant for sectors like education, health, or banking, where both emotion-sensitivity and technological constraints coexist (*Alipour et al., 2023*; *Matsuda et al., 2018*).

UX fragment analysis also confirms this logic:

- For Persona A, the form flow was redesigned to anticipate time constraints.
- For Persona B, the onboarding interface included exploratory branches, but lacked progressive reduction cues.
- For Persona C, modal prompts were removed entirely and replaced with ambient feedback.

Thus, the detailed fragment-level analysis, combined with the overall expert ratings, strongly supports Hypothesis H2. It demonstrates that while behaviorally adaptive design offers a robust standalone solution for emotional personalization in resource-constrained or ethically sensitive environments, its full potential, particularly in complex emotional states like boredom, is realized through a hybrid deployment model that can dynamically fine-tune UI responses for optimal emotional alignment and user experience across diverse contexts (*Figure 5*).

These results support our second hypothesis (H2), indicating that while behaviorally adaptive design can replace biometrics in constrained environments, full emotional alignment benefits from hybrid deployment.

Discussion

The analysis confirms that a scenario-based behavioral framework can effectively model emotional adaptation logic, providing both a methodological base and future-proof logic for real-time integration. Hypothesis H1 was validated: adaptive behaviors grounded in user personas and affective theory produced perceived emotional alignment without biometrics. H2 was also supported: participants responded most positively when adaptive cues resonated with both mental model and affective state, especially in designs that avoided overstimulation.

The concept of hybrid potential emerges as a critical implication. In practice, low-tech products (e.g., government forms, educational platforms) may deploy behavioral-only models. Meanwhile, in high-stakes systems (e.g., clinical diagnostics, adaptive learning), the same adaptive logic may guide biometric augmentation. The dual role—substitution and supplementation—marks the framework as flexible across UX strata. This duality aligns with early insights by Tao and Tan (*2005*), who emphasized that affective computing frameworks must balance technological capability with ethical interpretability, ensuring that adaptive systems remain context-aware and user-centered.

A key research problem for further discussion lies in precisely quantifying the interplay between behavioral cues and physiological signals in hybrid systems. How can a dynamic weighting mechanism be established to optimally combine these disparate data sources for nuanced emotional adaptation, especially across diverse cultural and contextual settings? Furthermore, questions arise regarding the generalizability of behavioral indicators: can a common set of behavioral patterns reliably predict emotional states across different user groups and interface types, or are highly specific models always required? This reinforces the value of scenario modeling: by anchoring adaptations in persona-based intent, designers can simulate the emotional effect before committing to live sensing infrastructure. Future work should prototype these fragments in hybrid systems with real-time data, testing whether adaptive gains compound when emotional feedback becomes dynamic.

Conclusion

This paper successfully introduces a novel conceptual scenario-based behavioral framework for emotionally adaptive web UX, addressing the limitations of biometric-dependent personalization. The study's methodology meticulously involved developing three distinct synthetic user personas—stressed, bored, and focused—each with unique mental models, and designing corresponding adaptive interface fragments. These adaptations were then rigorously evaluated through a structured heuristic assessment using a comprehensive set of seven metrics, including perceived emotional fit and resonance with mental models.

The interim results consistently validated the framework's core hypotheses. For instance, the "stressed user" persona demonstrated high emotional fit (4.6) and low friction (1.2) with its adapted interface, confirming that behavioral changes can effectively evoke emotional congruence even without real-time sensing. Similarly, the "focused user" persona achieved the highest ratings across all metrics (e.g., 4.7 for mental model resonance), reinforcing the power of cognitive-affective alignment for uninterrupted experiences. While the "bored user" scenario presented challenges (e.g., low engagement 2.9), it critically highlighted the necessity for nuanced, hybrid adaptation logic to avoid overstimulation and disruption of mental models.

In summary, this research confirms that emotional responsiveness in UX can be approximated through behavioral interface design. It establishes a vital "hybrid potential", demonstrating that behavioral adaptation can effectively substitute biometrics in low-tech or ethically constrained environments, and equally, augment them in high-fidelity systems to achieve dynamic fine-tuning. This framework not only fuses emotional design with user mental models but also provides practical tools for UX designers, interface engineers, and HCI researchers. It enables them to tailor UX fragments to emotional cues, identify friction points, and improve early prototyping alignment, thereby strengthening predictive power and enhancing the feasibility of ethically sustainable and scalable adaptive design solutions.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Alipour, M., Céret, É., & Dupuy-Chessa, S. (2023). *A framework for user interface adaptation to emotions and their temporal aspects*. *Proceedings of the ACM on Human-Computer Interaction (EICS)*, *7*, 1–25. https://doi.org/10.1145/3593238

Bargas-Avila, J. A., & Hornbæk, K. (2021). *Towards a unified model of user experience*. ACM Transactions on Computer-Human Interaction, *28*(5), 1–45. https://doi.org/10.1145/3448607

Calvo, R. A., & D'Mello, S. (2010). Affect detection: An interdisciplinary review of models, methods, and their applications. *IEEE Transactions on Affective Computing, 1*(1), 18–37. https://doi.org/10.1109/T-AFFC.2010.1

Chen, K., & Li, Y. (2021). *The role of emotion in UX: A systematic review*. Behaviour & Information Technology, *40*(7), 686–701. https://doi.org/10.1080/0144929X.2020.1795262

Dalvand, K., & Kazemifard, M. (2013). *An adaptive user interface based on user's emotion*. In *2013 8th International Conference on Computer Science & Education (ICCSE)* (pp. 131–136). IEEE. https://doi.org/10.1109/ICCSE.2013.6553912

Duric, Z., Gray, W. D., Heishman, R., Li, F., Rosenfeld, A., Schoelles, M. J., Schunn, C. D., & Wechsler, H. (2002). Integrating perceptual and cognitive modeling for adaptive and intelligent human–computer interaction. *Proceedings of the IEEE*, *90*(7), 1272–1289. https://doi.org/10.1109/JPROC.2002.801448

Mahmud, R., Wu, Y., Abdullah, B. S., Berkovsky, S., Prasad, M., & Kocaballi, A. B. (2025). Evaluating user experience in conversational recommender systems: A systematic review across classical and LLM-powered approaches. *arXiv:2508.02096*. https://arxiv.org/abs/2508.02096

Matsuda, Y., Yoshida, K., & Oka, R. (2018). EmoTour: Estimating emotion and satisfaction of users based on behavioral cues and audiovisual data. *Sensors*, *18*(11), 3978. https://doi.org/10.3390/s18113978

Schuller, B., Weninger, F., Zhang, Y., Ringeval, F., Batliner, A., Steidl, S., Eyben, F., Marchi, E., & Vinciarelli, A. (2018). Affective and behavioural computing: Lessons learnt from the first computational paralinguistics challenge. *Computer Speech & Language*, *53–54*, 104–131. https://doi.org/10.1016/j.csl.2018.02.004

Stephanidis, C., Salvendy, G., Antona, M., & Chen, J. Y. C. (2021). User experience evaluation in intelligent environments: A comprehensive framework. *Technologies*, *9*(2), 41. https://doi.org/10.3390/technologies9020041

Sun, N., & Jiang, Y. (2025). Eye movements and user emotional experience: A study in interface design. *Frontiers in Psychology*, *16*, 1455177. https://doi.org/10.3389/fpsyg.2025.1455177

Appendix

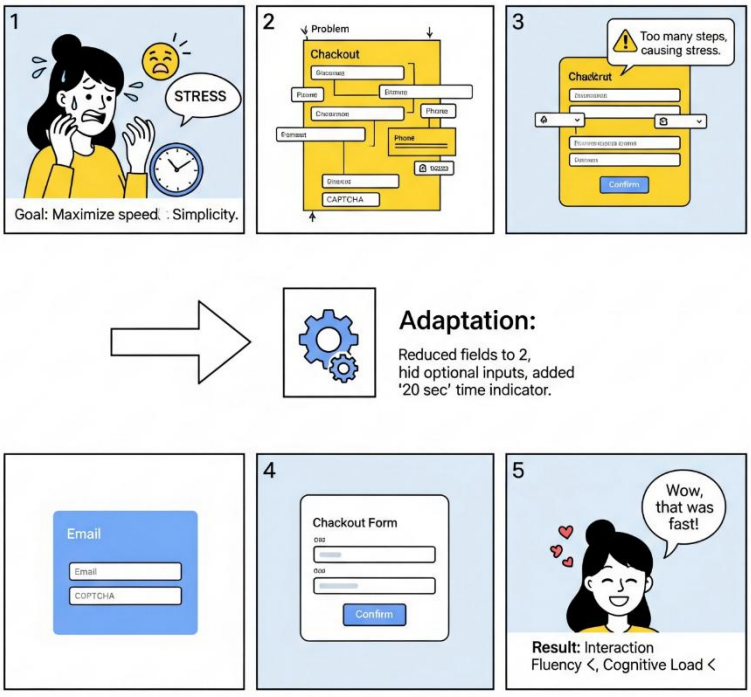

Figure 1. Persona A: The Stressed User

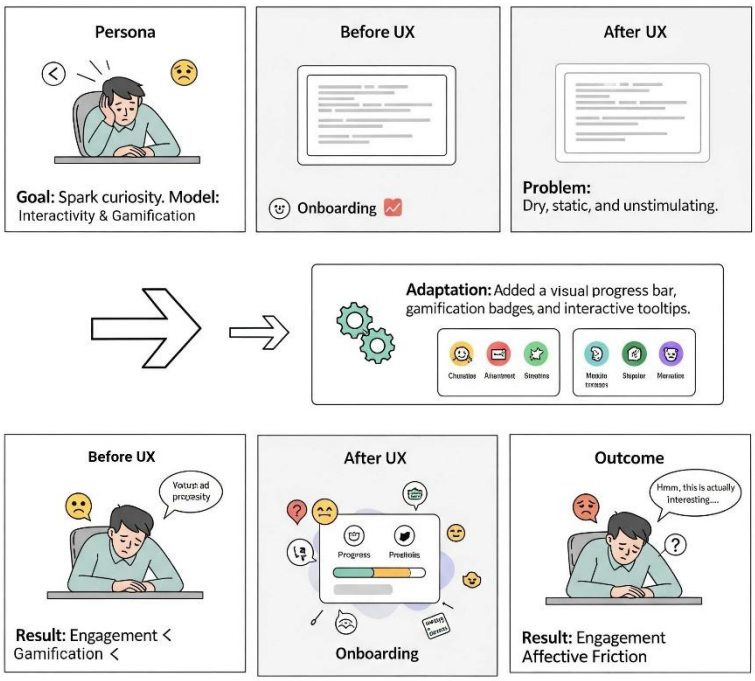

Figure 2. Persona B: The Bored User

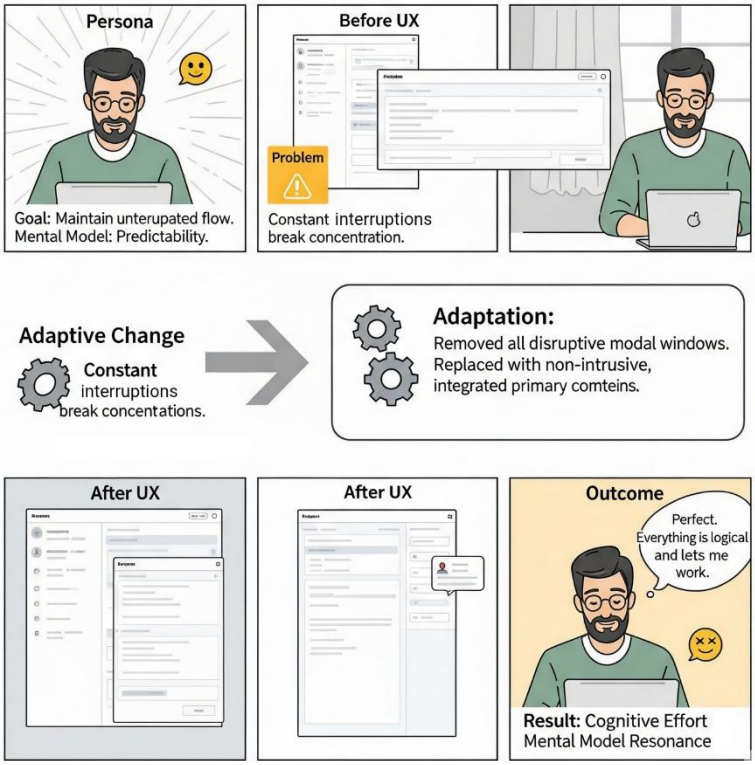

Figure 3. Persona C: The Focused User

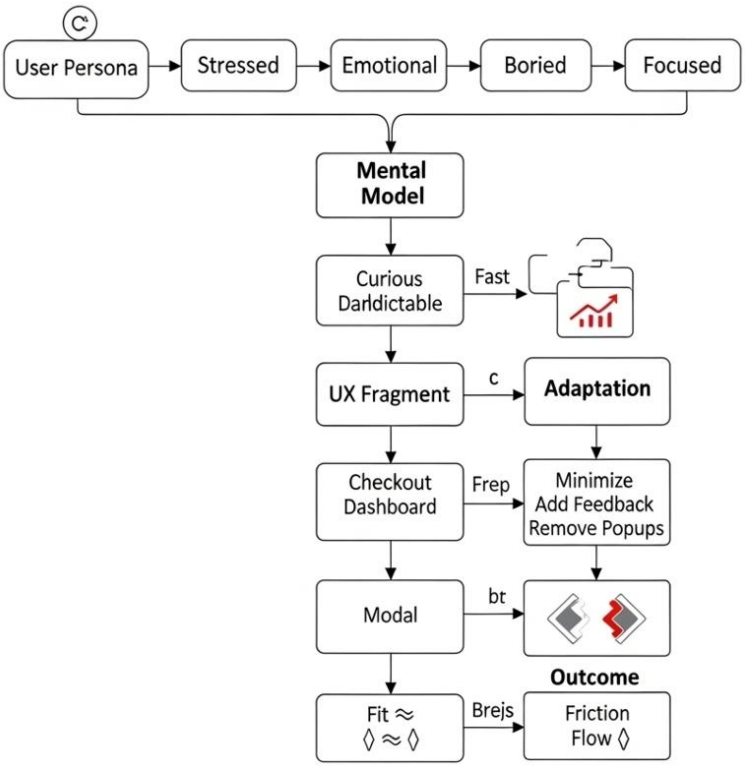

Figure 4. The logic of scenario-behavioral adapation

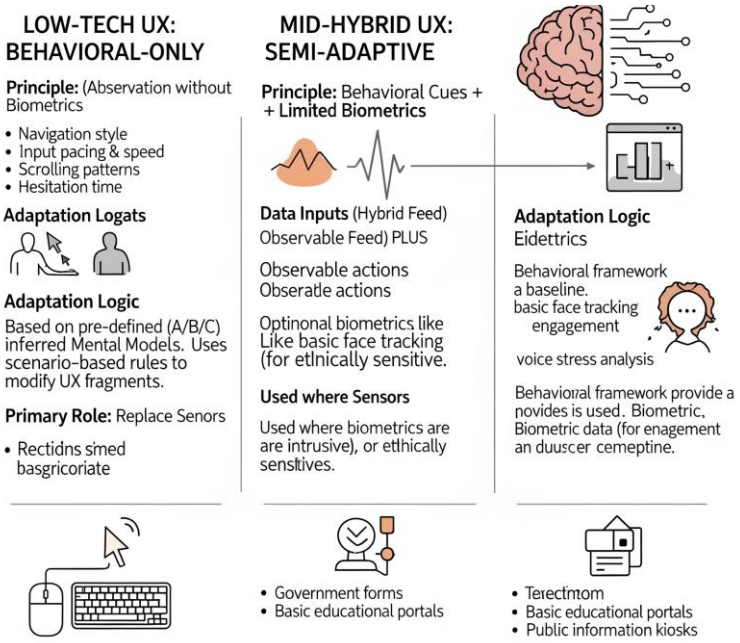

Figure 5. Hybrid Deployment Popential: A Continuum of Emotional Adaptation in UX

Table 1. Expert Ratings for Scenario-Based Adaptive Interfaces (mean scores)

CRITERIA	STRESSED USER	BORED USER	FOCUSED USER
PERCEIVED EMOTIONAL FIT	4.6	3.1	4.4
COGNITIVE EFFORT	4.5	3.0	4.7
INTERACTION FLUENCY	4.2	3.4	4.6
DISRUPTION RECOVERY	4.4	3.2	4.5
ENGAGEMENT STIMULATION	4.1	2.9	4.4
AFFECTIVE FRICTION POINTS	1.2	2.7	1.1
RESONANCE WITH MENTAL MODEL	4.5	3.0	4.7

Mykola A. Kolisnyk [a][15]

Using the Czech Experience of Innovations in Mechanical Engineering and Energy Saving to Train Engineering Personnel in the Agricultural Sector [11]

Abstract: The article provides a thorough analysis of the experience of the Czech Republic in innovative development of Mechanical Engineering and energy saving, considering the needs of modern agricultural engineering. The key directions of modernisation of technical means for agriculture are considered in detail, in particular the use of digital platforms for monitoring production processes, the introduction of automated and robotic systems in animal husbandry and crop production, as well as the integration of precision farming technologies. The importance of the transition of the Czech agricultural sector to the concept of "smart" production, combining machine-building innovations, digital tools and energy-efficient solutions, was noted. Special attention is paid to the state policy of the Czech Republic on energy saving and improving energy efficiency in industry and the agricultural sector. The author analyses measures for developing renewable energy, in particular the use of biogas plants, solar panels and wind farms, as well as the introduction of energy management systems that provide comprehensive control and rational use of energy resources. The article highlights the experience of integrating energy-saving technologies into the production processes of machine-building enterprises that produce equipment for agricultural needs. The article substantiates the prospects for adapting the Czech experience in Ukraine, in particular in the process of training engineering personnel for the agricultural sector. The necessity of modernizing educational programs that should focus on developing competencies in digitalization, automation and energy saving is emphasised. It focuses on the importance of international internships, participation of students and teachers in research projects, as well as the development of inter-university cooperation between Ukraine and the Czech Republic. It is noted that it is the exchange of experience and the implementation of European educational standards that can provide training for competitive specialists who can effectively apply innovative technologies in the context of sustainable development of the agricultural sector of Ukraine.

Keywords: innovation, mechanical engineering, energy saving, Agricultural Engineering, Czech Republic, international experience, engineer training.

Introduction

The modern development of Ukraine's agricultural sector is taking place under conditions of intense global competition and increasing challenges related to resource conservation, energy security and environmental sustainability (*Innovation in Agriculture and Rural Development, 2023*; *Innovation, Productivity and Sustainability…, 2022*). These factors create the need to adapt the agricultural sector to new realities, where technological innovation and the efficient use of resources play a key role. In such circumstances, the training of a new generation of engineers becomes a strategically important task, as these specialists are responsible for the introduction of modern technologies, the optimisation of production processes and the sustainable development of the agricultural sector. One of the most important factors determining the quality of such training is the use of advanced international experience, particularly that of the European Union countries, which have already achieved significant progress in innovative technologies, digitalisation and energy efficiency.

[a] Ph.D. in Mechanical Engineering, Senior Lecturer, Department of Power Engineering, Electrical Engineering and Electrical Mechanics, Faculty of Engineering and Technology, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.

The Czech Republic is a vivid example of a country that successfully combines rich traditions in mechanical engineering with modern innovative approaches. The country actively implements digitalisation, automation and renewable energy technologies, which enables it to remain competitive on the global market. Czech experience demonstrates effective models of integrating science, education and industry, ensuring a rapid transition from theoretical developments to practical applications. In particular, the Czech Republic has created a well-developed ecosystem that includes cooperation between universities, research centres and industrial enterprises. This approach facilitates the training of highly qualified engineers who possess both theoretical knowledge and the practical skills necessary to work with modern technologies.

The Czech model of engineering education is based on several key principles. Firstly, there is an emphasis on interdisciplinarity, which enables engineers to combine knowledge from mechanical engineering, information technology and energy saving. Secondly, considerable attention is given to practical training through internships at enterprises, participation in real projects and the use of simulation technologies. Thirdly, Czech universities actively cooperate with business, ensuring that curricula meet the needs of the labour market. For example, dual education programmes are widely applied in the Czech Republic, allowing students to study and work at enterprises simultaneously, thereby gaining practical experience.

The purpose of this article is to conduct a systematic analysis of the innovative development of mechanical engineering and energy saving in the Czech Republic to identify opportunities for applying this experience to improve engineering training in Ukraine. The research focuses particularly on Czech approaches to the introduction of digital technologies, automation and energy-efficient solutions in mechanical engineering, as well as on the analysis of the engineering training system that prepares graduates for work in modern agricultural production. Applying Czech experience may contribute to the development in Ukraine of engineers' professional competences, including knowledge of modern technologies, the ability to work with automated systems, and skills in implementing energy-efficient and environmentally sustainable solutions.

To achieve this aim, Czech practices must be adapted to Ukrainian realities, considering the characteristics of the national agricultural sector and economic constraints. For example, Ukraine could develop dual education programmes, establish technology transfer centres at universities, and strengthen cooperation between universities and agricultural enterprises. Moreover, it is important to invest in the digitalisation of education, particularly in the development of simulation platforms and virtual laboratories, which would allow students to acquire practical skills without incurring significant material costs. Thus, the use of Czech experience may form the basis for modernising Ukraine's system of engineering training, contributing to increased competitiveness of the agricultural sector on the global market.

Materials and Methods

Mechanical engineering in the Czech Republic has a centuries-long history; however, it is the most recent decades that have marked its transformation into a high-tech industry oriented towards the needs of modern production (*Hromádka & Novák, 2021*). Agricultural engineering in this country is characterised by the integration of digital technologies, robotic systems and "smart" management tools.

One of the leading trends is the introduction of digital monitoring and machinery control systems. Machines are equipped with sensors that transmit real-time data, enabling the optimisation of fuel consumption, load control and equipment condition monitoring. This reduces the risk of breakdowns and increases the efficiency of resource use.

A prominent place is occupied by developing precision farming, based on the precise application of fertilisers, crop protection agents and water. Czech companies employ software systems that analyse field maps and weather data, ensuring the rational use of materials and the reduction of negative environmental impacts.

A significant direction in the modernisation of mechanical engineering is the use of new materials and production technologies. Thanks to the application of lightweight alloys and composites, it has been possible to reduce the weight of machinery, contributing to energy savings during operation. Such solutions are especially important for the agricultural sector, where machinery operates under heavy loads.

Thus, Czech mechanical engineering demonstrates a comprehensive approach to creating modern technical systems that are focused on efficiency, environmental sustainability and integration with digital technologies.

Literature Review

The analysis of recent scientific publications demonstrates that the innovative experience of the Czech Republic in mechanical engineering and energy saving forms an essential reference point for countries striving to modernise their agricultural sectors. According to Hromádka and Novák (*2021*), Czech agricultural engineering has undergone rapid transformation due to the integration of digital technologies, robotics and automation. The researchers note that digitalisation of production, precision agriculture and smart control systems constitute the main drivers of technological advancement, contributing to both productivity growth and sustainability. Their conclusions are consistent with the findings of Palková et al. (*2022*), who highlight the necessity of preparing specialists in accordance with the principles of Agriculture 4.0, based on digital competencies, interdisciplinary education and strong links between academia and industry.

The importance of innovation and sustainability in the agricultural economy is further emphasised in the OECD report Innovation, Productivity and Sustainability in Food and Agriculture (*2022*), which stresses that long-term competitiveness of agricultural production is directly linked to the implementation of resource-efficient technologies. The document outlines that the most successful European countries in this regard, including the Czech Republic, have achieved significant progress through national strategies focused on energy efficiency, renewable energy and digital transformation. A similar perspective is shared by the European Commission (*Innovation…, 2023*), which associates rural development with the diffusion of innovation and smart specialisations across regions, ensuring an integrated approach to technological and educational reforms.

An essential component of Czech innovation policy is the government's commitment to energy efficiency and renewable energy. The Energy Efficiency and Renewable Energy Strategy 2030 (*2022*) developed by the Ministry of Industry and Trade of the Czech Republic defines key priorities in reducing energy consumption and expanding renewable sources. Durčanský (*2023*)

analyses the evolution of green energy in the Czech Republic and identifies a dynamic increase in biogas, solar and wind energy use. These developments, according to the author, not only reduce dependence on imported energy resources but also promote environmental sustainability and create new opportunities for engineering innovation. Honchar (*2023*) supports this view, pointing out that similar approaches could be successfully implemented in Ukraine to improve energy security and agricultural efficiency.

The integration of energy-saving technologies into educational and industrial systems is another recurring theme in the literature. Gródek-Szostak et al. (*2021*) show that awareness and behavioural factors play a critical role in promoting energy conservation, particularly among students and young specialists. The authors' comparative analysis of Polish, Czech and Ukrainian students demonstrates that the level of energy-saving awareness correlates with the effectiveness of national educational strategies. Therefore, the inclusion of sustainability issues and energy efficiency in higher education curricula becomes a prerequisite for successful implementation of innovative technologies.

From the standpoint of industrial innovation, Kozyrskyi and Sydorenko (*2022*) emphasise that the experience of EU countries, especially the Czech Republic, proves the effectiveness of integrating innovative engineering technologies into the agricultural machinery sector. Their study notes that the combination of automation, sensor-based monitoring and lightweight materials ensures energy savings and enhances the ecological efficiency of agricultural production. Similar conclusions are drawn by Kowalska and Kovárník (*2019*), who examine smart specialisations in Poland and the Czech Republic, arguing that the synergy between innovation policy and education reform generates sustainable competitive advantages for the regional economy.

Collectively, these studies underline that Czech innovation in mechanical engineering and energy saving is not limited to technical progress alone but extends to the broader transformation of educational and institutional frameworks. The formation of a coherent innovation ecosystem that unites research institutions, industrial enterprises and educational establishments has allowed the Czech Republic to build an advanced model of knowledge transfer and practical training. Such integration ensures that engineers are equipped not only with theoretical knowledge but also with practical skills in energy management, digital technologies and ecological design (*Palková et al., 2022*; *Hromádka & Novák, 2021*). Consequently, the Czech model can serve as an exemplary case for Ukraine, where the modernisation of engineering education is considered a strategic component of agricultural innovation and sustainable development (*Honchar, 2023*; *Innovation…, 2023*).

In summary, the reviewed literature reveals that the Czech Republic's success in mechanical engineering and energy efficiency is based on the interconnection between state policy, academic research and industrial practice. The integration of digital tools, energy-saving technologies and interdisciplinary education forms the foundation of this system. Adapting these principles to Ukrainian realities could facilitate the creation of a new generation of engineers capable of ensuring technological modernisation, energy independence and sustainable growth of the national agricultural sector.

Results

Energy saving is one of the key priorities of state policy in the Czech Republic, reflected in a comprehensive approach to reducing energy consumption and increasing energy efficiency across various sectors of the economy, including agriculture. The country actively implements incentive mechanisms aimed at enterprises and households to reduce energy consumption—an issue of particular importance in agriculture, where energy costs constitute a substantial share of production expenses. This approach combines financial incentives with regulatory mechanisms that encourage technological modernisation and the adoption of energy-efficient solutions.

One of the leading areas of energy saving in the Czech agricultural sector is the widespread use of renewable energy sources. Biogas plants have become an important tool that simultaneously addresses both energy and environmental challenges. These plants operate on the processing of livestock and crop residues such as manure, straw and harvest waste. The resulting biogas is used to generate electricity and heat, meeting the needs of agricultural enterprises. In addition, waste processing helps reduce greenhouse gas emissions and enhances the environmental safety of production. For instance, biogas plants can utilise up to 90% of organic waste, significantly reducing negative environmental impacts.

Alongside biogas technologies, solar energy is also actively developing in the Czech Republic. Solar power plants are installed on both large agricultural enterprises and small farms. This ensures a stable electricity supply while reducing dependence on traditional energy sources. State support programmes, such as subsidies and preferential loans, promote the rapid spread of solar panels in rural areas. For example, farms can receive up to 50% compensation for the cost of equipment for solar power plants, making such investments economically viable.

Considerable attention in the Czech Republic is devoted to the energy-efficient design of agricultural buildings and facilities. New complexes for storage, processing or production of agricultural goods are constructed using modern thermal insulation materials such as polystyrene or mineral wool, which reduce heat loss by 20–30%. Ventilation, heating and cooling systems are equipped with automated control mechanisms that optimise energy consumption depending on weather conditions and production requirements. For example, the use of heat pumps in combination with automated control systems allows energy costs for heating livestock facilities to be reduced by up to 40%. Furthermore, passive energy-saving principles are widely applied in the design of new buildings. These include the correct orientation of buildings relative to the sun to maximise natural light, as well as the installation of low-emission glazing to minimise heat loss. Such solutions not only reduce energy consumption but also improve comfort for workers and animals in agricultural complexes.

The Czech Republic is also actively developing energy management systems based on digital technologies and real-time monitoring of energy consumption. The use of "smart meters" allows agricultural enterprises to track energy use at various stages of production, identify inefficient processes and optimise them. Specialised software integrated with these meters provides a detailed analysis of energy consumption structures, helping to identify potential savings. For example, farms using such systems can cut electricity consumption for lighting and equipment operation by 15–25%. Moreover, energy management systems allow for predictive energy planning. With the help of artificial intelligence algorithms, enterprises can

forecast peak loads and optimise equipment operation to avoid excessive energy use. Such solutions are especially significant for large agroholdings, where even minor reductions in consumption may result in substantial financial savings.

In the Czech Republic, energy saving is viewed not merely as a tool for conserving resources but also as a strategic foundation for sustainable development. The combination of economic benefits, environmental safety and social responsibility is a key principle of Czech policy in this field. The introduction of energy-efficient technologies enables agricultural enterprises to reduce production costs, thereby increasing their competitiveness on European and global markets. At the same time, reducing greenhouse gas emissions and recycling waste contribute to environmental protection. The Czech experience demonstrates that successful implementation of energy-saving projects requires a comprehensive approach that includes state support, private investment and cooperation with research institutions. For instance, the country operates specialised funds that finance research in energy efficiency, as well as training programmes for specialists capable of applying modern technologies in practice.

Czech experience in energy saving can be adapted to the needs of Ukraine's agricultural sector. For example, the introduction of biogas plants on Ukrainian farms could resolve the issue of organic waste disposal while providing an additional energy source. Solar power plants, which are already emerging in Ukraine, could expand further with state support and affordable loan programmes. Moreover, the adoption of energy management systems and energy-efficient building design could significantly reduce agricultural enterprises' energy costs. To realise such initiatives in Ukraine, favourable conditions must be created, including a legislative framework, financial incentives and specialist training programmes. The Czech model demonstrates that cooperation between the state, business and research institutions is a crucial success factor. Therefore, adapting Czech experience could contribute to modernising Ukraine's agricultural sector, increasing its energy efficiency and strengthening its competitiveness.

Discussion

The experience of the Czech Republic in the field of innovation is of exceptional value to Ukraine, faced with the need to update its approaches to the training of engineering personnel for the agricultural sector. This experience may serve as the foundation for creating a modern education system that meets the challenges of the global market and fosters the sustainable development of agriculture. Above all, it concerns the formation of professional competences that correspond to current labour market demands, international standards, and technological trends. This involves not only technical knowledge, but also the ability to adapt to rapidly changing conditions, apply innovative solutions, and work with advanced technologies. Such an approach is key to ensuring the competitiveness of Ukraine's agricultural sector in conditions of intense global competition.

Firstly, an important priority is the strengthening of attention to digital technologies in the training of engineers. Future specialists must acquire strong skills in using software for modelling technical processes, data analysis, managing automated systems, and introducing digital solutions into production (*Hromádka & Novák, 2021*; *Innovation, Productivity and Sustainability…, 2022*). This includes the use of programmes for equipment design, optimisation of production processes, as well as big data analysis for forecasting needs and increasing

efficiency. Such skills enable engineers to develop innovative solutions that improve agricultural productivity, reduce resource costs, and optimise the use of equipment. For example, digital platforms for managing agricultural processes can reduce the time needed for operations and lower fuel and other material expenses, which is critically important for Ukraine's energy-intensive agricultural sector.

Secondly, it is extremely important to familiarise students with energy-saving and renewable energy technologies. High energy consumption, which creates significant financial and environmental challenges, characterises Ukrainian agricultural production. The implementation of innovative energy solutions, such as biogas plants, solar panels, or energy-efficient heating systems, is one of the key tasks of modern engineering. Engineers must be prepared to design and operate such systems, as well as to integrate them into agricultural production. Training should include studying the principles of renewable energy sources, methods of reducing energy consumption, and technologies that minimise environmental impact. This will not only increase production efficiency but also contribute to ecological stability, which is a vital aspect of modern agriculture.

Thirdly, attention is worth drawing to international internships and academic mobility, which provide future engineers with the opportunity to become directly acquainted with advanced practices and technologies. Participation in such programmes allows students to gain experience in operating modern equipment, studying new methods of energy systems management, and learning innovative approaches to production organisation (*Innovation in Agriculture and Rural Development, 2023*). For instance, Czech student exchange programmes provide practical training at enterprises where future engineers can become familiar with automated systems, modern management methods, and energy-efficient technologies. Such experience is invaluable for developing professional skills that can be applied in Ukraine. Furthermore, international cooperation fosters knowledge exchange and the creation of professional networks, which may be beneficial for the further development of the agricultural sector.

Thus, the adaptation of Czech experience within the Ukrainian education system will contribute to forming a new generation of engineers capable of ensuring the technological modernisation of the agricultural sector. These specialists will possess the necessary knowledge and skills for implementing digital technologies, energy-efficient solutions, and modern management methods, thereby increasing the productivity and competitiveness of Ukrainian agriculture. Moreover, an emphasis on environmental sustainability will help reduce the impact of agricultural production on the environment, in line with global trends in sustainable development. Implementing such changes requires a comprehensive approach, including the reform of educational programmes, the creation of conditions for international cooperation, and support from both the state and business. Nevertheless, the results of these efforts will have a long-term positive effect on Ukraine's economy.

Conclusion

The Czech Republic's experience in mechanical engineering and energy saving in agriculture illustrates an effective model of technological modernisation, combining economic, environmental and social aspects. The introduction of biogas plants, solar power systems,

energy-efficient buildings and digital energy management demonstrates that sustainable development is achievable through a comprehensive approach and interaction between all stakeholders.

For Ukraine, this experience may serve as a practical guide to enhancing the efficiency of its agricultural sector. The adaptation of Czech practices could reduce production costs, strengthen the competitiveness of Ukrainian products and contribute to environmental protection. The main condition for success lies in developing a legislative framework, financial incentive mechanisms and the promotion of cooperation between the state, business and scientific institutions.

Thus, the Czech Republic represents a successful example of the transition to sustainable agriculture based on innovation, energy saving and environmental responsibility. Its experience provides valuable insights that could be effectively applied in Ukraine, promoting the modernisation of agriculture and its integration into European and global markets.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Durčanský, P. (2023). Evolution of green energy production in Czech Republic. *Applied Sciences*, *13*(4), 2185.

Energy Efficiency and Renewable Energy Strategy 2030. (2022). Ministry of Industry and Trade of the Czech Republic. Prague.

Gródek-Szostak, Z., et al. (2021). Energy conservation behaviors and awareness of Polish, Czech and Ukrainian students: A case study. *Energies*, *14*(18), 5599.

Honchar, I. P. (2023). *Development of energy saving in the agricultural sector: European experience and Ukrainian prospects*. Vinnytsia: Agrarian Science Publishing House. (In Ukr.). [Гончар, І. П. Розвиток енергозбереження в аграрному секторі: європейський досвід та українські перспективи. Вінниця: Видавництво "Аграрна наука", 2023.]

Hromádka, J., & Novák, P. (2021). Modern approaches to agricultural engineering in the Czech Republic. *Journal of Agricultural Engineering*, *5*(2), 45–58.

Innovation, Productivity and Sustainability in Food and Agriculture: Main Findings. (2022). OECD. Paris: OECD Publishing.

Innovation in Agriculture and Rural Development. (2023). European Commission. Brussels.

Kowalska, A. S., & Kovárník, J. (2019). Smart wpecializations in Poland and the Czech Republic. *Hradec Economic Days*. https://doi.org/10.36689/uhk/hed/2019-01-045

Kozyrskyi, V., & Sydorenko, P. (2022). Innovative technologies in agricultural engineering: the experience of EU countries. *Bulletin of Agrarian Science*, *7*(2), 56–64. (In Ukr.). [Козирський, В., Сидоренко, П. Інноваційні технології в аграрному машинобудуванні: досвід країн ЄС // Вісник аграрної науки. — 2022. — № 7(2). — С. 56–64.]

Palková, Z., Harničárová, M., Valíček, J., Stehel, V., et al. (2022). Perspective of education in Agriculture 4.0 in selected countries in European Union and Palestine. *Proceedings of the 8th International Conference on Energy Efficiency and Agricultural Engineering*. Ruse, Bulgaria.

Vitalii M. Yaropud [a][16]

Implementation of Innovations in Technologies and Engineering: European Approaches and Opportunities for Ukraine (Case of the Czech Republic) [12]

Abstract: The article is devoted to the analysis of European approaches to implementing innovations in technologies and engineering, as well as to outlining the opportunities for their integration in Ukraine using the case of the Czech Republic. It is shown that modern engineering education and the agro-industrial sector are undergoing rapid transformations, where digitalization, environmental responsibility, and sustainable development become the key determinants of competitiveness. The European Green Deal and the Farm to Fork Strategy set clear requirements for energy efficiency, emission reduction, supply chain transparency, and the use of «smart» monitoring and management technologies. The study generalizes the Czech experience, where the combination of university training, short industrial R&D sprints, and joint laboratories with businesses ensures rapid knowledge transfer and high employability of graduates. The research methodology is based on comparative analysis of EU and Ukrainian policies and regulatory acts, the use of design thinking for structuring competencies, a logical-structural approach to shaping learning outcomes, and case analysis of university-business partnerships. The article proposes the architecture of an integrated dual model "university — R&D center — production" covering academic, research, and industrial blocks with clear quality indicators. An implementation roadmap (12–18 months) is presented, which includes resource auditing, redesign of educational programs aligned with EQF/NQF, establishment of joint laboratories, international partnerships, and integration of English-taught modules. It is demonstrated that Ukraine's regulatory framework (EQF/NQF, licensing conditions, Laws «On Education» «On Higher Education» "On Innovation Activity" and the EU–Ukraine Association Agreement) provides the necessary foundation for scaling European practices. The conclusion emphasizes that the key success factors are the modernization of educational programs, continuous dialogue with business, internationalization, and the formation of a culture of measurable outcomes, which will enable the training of a «new wave» of engineers capable of addressing contemporary challenges.

Keywords: innovations, engineering education, European Green Deal, Farm to Fork Strategy, dual training, Czech Republic, digital engineering, R&D sprints, sustainable development, National Qualifications Framework.

Abbreviations:

EQF is European Qualifications Framework,

ESG is environmental, social, and governance,

LOs are learning outcomes,

NQF is National Qualifications Framework.

Introduction

Today, Ukrainian engineering education and the agro-industrial sector are undergoing a stage of rapid transformation. The key benchmarks are digitalisation, environmental responsibility, and sustainable development are factors that determine competitiveness in the modern world.

[a] Doctor of Technical Sciences, Associate Professor, Department of Machines and Equipment for Agricultural Production, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.

The European Green Deal (*2019*) and the Farm to Fork Strategy (*2020*) set a clear vector of development: the reduction of resource consumption and carbon emissions, transparency and controllability of supply chains, the advancement of organic production, and the application of "smart" monitoring and management technologies.

In the Ukrainian context, these priorities are aligned with the *Strategy for the Development of Agricultural, Food and Processing Industry Exports until 2026* (*2019*), which places a particular emphasis on the transition from a raw-material model to the production of high value-added goods.

Within such a political and institutional environment, there is an increasingly tangible demand for specialists capable of integrating innovative solutions into production processes. They must rely on European standards of quality, safety, and transparency, combining scientific approaches with practical management tools.

The purpose of the study is to generalise the approaches of the Czech Republic to the implementation of innovations in technology and engineering and to outline mechanisms for their incorporation into Ukrainian higher education institutions and enterprises.

To achieve this objective, the following tasks have been set:

- analyse the regulatory frameworks of the EU and Ukraine (the European Green Deal, the Farm to Fork Strategy, EQF/NQF, laws and resolutions of the Cabinet of Ministers of Ukraine);
- identify Czech educational models that ensure practice-oriented training and the rapid transfer of technologies;
- propose an architecture of integrated dual training "university—R&D centre—production";
- present a roadmap for implementation, considering Ukrainian conditions.

Methods

Several complementary approaches were employed in this study. Firstly, a comparative analysis was conducted of key policies and regulatory documents: the European Green Deal (*2019*), the "Farm to Fork" strategy (*2020*), the Association Agreement between Ukraine and the EU (*2014*), as well as the Laws of Ukraine "On Education" (*2017*), "On Higher Education" (*2014*), "On Innovation Activity" (*2002*), and the resolutions of the Cabinet of Ministers concerning the National Qualifications Framework and licensing conditions (*2011*).

Secondly, design thinking tools were applied to structure competences and learning modules. Thirdly, a logical-structural approach was utilised to develop educational outcomes (Learning Outcomes) with reference to the EQF/NQF levels.

In addition, a case analysis of university-business partnerships in the Czech Republic and Ukraine performed out, which made it possible to assess effective practices of integrating innovation into the educational process.

Literature Review

The formation of an innovative model of engineering education in Europe is inseparable from the global sustainable development agenda and the digital transformation of production.

The European Green Deal (*2019*) and the Farm to Fork Strategy (*2020*) have become strategic milestones for reconfiguring educational and industrial systems toward climate neutrality, responsible resource management, and circular economy models. These documents defined innovation not merely as technological modernisation but as an institutional mechanism for implementing the principles of ESG responsibility. According to the European Commission, sustainability has become a cross-cutting criterion in funding educational and research programmes, including Horizon Europe and Erasmus+, and in shaping the competencies outlined by the EQF (*The European Green Deal, 2019*; *Farm to Fork Strategy, 2020*).

The EQF and the NQF of Ukraine (*On Approval…, 2011*) act as pivotal regulatory tools aligning educational outcomes with European standards. Their application ensures transparency, mobility, and mutual recognition of qualifications across borders (*On the European Qualifications Framework, 2017*). The NQF, approved by the Cabinet of Ministers of Ukraine, integrates the descriptors of professional competence and measurable learning outcomes, thereby enabling the harmonisation of engineering education with European benchmarks (*On Approval…, 2011*). This alignment fosters the comparability of Ukrainian degrees and their "readability" for European employers, a precondition for integrating national universities into international research and innovation networks.

A critical component of European innovation policy is the integration of education, research, and production, particularly within engineering disciplines. The Czech Republic demonstrates a successful dual-education model that combines academic instruction with practical industrial training. The implementation of this model is supported by the Association Agreement between Ukraine and the European Union (*2014*), which provides legal and financial instruments for joint projects in science, technology, and higher education. In this context, the Czech approach is noteworthy for its emphasis on short industrial R&D sprints, joint laboratories with enterprises, and a competency-based curriculum linked to real-world challenges. Such collaboration between universities and businesses ensures that graduates acquire both theoretical knowledge and applied technical skills, improving their employability and fostering innovation (*Association Agreement…, 2014*).

The Farm to Fork Strategy (*2020*) positions engineering education as a driver of ecological transformation in the agro-industrial sector, highlighting the need for technologies that support energy efficiency, emission reduction, and digital traceability of production processes. The integration of these principles into engineering curricula requires a redesign of educational programmes, embedding transversal competencies in sustainability, digitalisation, and entrepreneurship. Similar priorities are reflected in Ukraine's Strategy for the Development of Agricultural, Food and Processing Industry Exports until 2026 (*2019*), which calls for a transition from raw-material exports to high value-added production through technological innovation and workforce development (*Strategy for the Development…, 2019*). Consequently, the modern engineer must possess a hybrid set of skills encompassing digital literacy, environmental awareness, and innovation management.

At the institutional level, the European Digital Europe Programme (2021–2027) further supports this transformation by funding initiatives in artificial intelligence, data spaces, high-performance computing, and advanced digital skills. These technologies underpin new methodologies of engineering education, including the use of digital twins, PLC/SCADA

systems, IoT/IIoT networks, and machine learning for process optimisation. As a result, the engineer's professional role evolves from that of an operator to that of a designer and integrator of complex technological systems (*A Digital Europe Programme, 2021*).

Legislative frameworks in Ukraine provide the necessary foundation for incorporating these European approaches. The Laws "On Education" (*2017*), "On Higher Education" (*2014*), and "On Innovation Activity" (*2002*) outline mechanisms for academic autonomy, the integration of research into the educational process, and the commercialisation of intellectual property. These acts correspond with the EU's vision of innovation ecosystems, where education serves as both the generator of knowledge and the incubator of entrepreneurial initiatives (*On Education, 2017*; *On Higher Education, 2014*; *On Innovation Activity, 2002*). The Law "On Licensing Conditions for Educational Activities" (*2015*) ensures quality assurance through strict requirements for facilities, staffing, and practical components, aligning national institutions with European accreditation practices (*On Licensing Conditions…, 2015*).

Results

The *Farm to Fork Strategy* (*2020*) establishes a new logic for the development of food systems: human health, environmental sustainability, and market competitiveness must be regarded as an integrated whole.

For engineers, this implies an entirely new set of technical requirements:

- energy efficiency of all processes;
- minimisation of losses and harmful emissions;
- digital tracking and data-driven management;
- the use of sensors, drones, and satellite monitoring;
- the implementation of digital twins, PLC/SCADA systems, and machine learning methods (*The European Green Deal, 2019*; *On Licensing Conditions…, 2015*).

In addition, the European Qualifications Framework (EQF) defines generalised levels of competences, while the National Qualifications Framework (NQF) of Ukraine renders these results 'legible' also to European employers (*A Digital Europe Programme, 2021*; *On the European Qualifications…, 2017*).

Accordingly, educational and professional programmes in engineering disciplines require redesign. They must integrate, in a transversal manner, competences in sustainable engineering, digital engineering, safety, product lifecycle management, and innovation entrepreneurship. This will enable the training of specialists capable of responding to the new challenges of the global market.

Czech technical universities demonstrate flexible models of combining education, R&D, and production:

a) short industrial sprints within semester courses;
b) joint laboratories with access to measurement and testing equipment;
c) project modules commissioned by companies with clearly defined KPIs;
d) mentoring by practising engineers in disciplines and interdisciplinary studies (data science for agriculture, mechatronics, eco-modelling).

The result is a rapid renewal of content, the conversion of student projects into prototypes

and start-ups, co-authorship in publications and patents, and high levels of graduate employability.

The national regulatory framework provides a sufficient basis for scaling up European approaches. The Resolution of the Cabinet of Ministers of Ukraine approving the NQF establishes levels and enables alignment of LOs with the EQF; the Licensing Conditions for the Provision of Educational Activity regulate resources, practices, and staffing; the Laws of Ukraine *On Education* and *On Higher Education* ensure institutional autonomy, the integration of education and research, and academic mobility; the Law *On Innovation Activity* provides tools for R&D collaboration, technology transfer, and IP management. The Association Agreement (articles on science, innovation, and education) opens channels for participation in European programmes and joint projects. Taken together, these form the legal basis for integrated dual trajectories and international placements.

The architecture of integrated dual training "university—R&D centre—production" is based on a three-phase model:

1. Academic block is modules in digital engineering (CAE/CFD, CAD/CAM/PLM), IoT/IIoT and cyber-physical systems, risk management, and LCA assessment;
2. Research block is engineering sprints, testing, prototyping, experimental design, scientific publications, and IP applications;
3. Production block is field cases in precision agriculture, implementation of automated solutions, energy efficiency audits, and post-project support.

Each block is linked to quality indicators: competence levels (EQF/NQF), employer-validated LOs, a set of artefacts (prototypes, patents, LCA reports, publications), and the share of implemented cases among partners.

The roadmap for implementation (12–18 months) includes:

- Stage 1, audit of programmes and resources: verification of compliance with Licensing Conditions, identification of gaps in laboratory infrastructure, and selection of industrial mentors.
- Stage 2, redesign of programmes: construction of a "competences–modules–LOs" matrix aligned with EQF/NQF; integration of micro-qualifications (simulations, GIS/drones, PLC/SCADA).
- Stage 3, launch of joint laboratories and R&D sprints; agreements on confidentiality and IP, testing schedules, and external evaluation mechanisms.
- Stage 4, scaling and internationalisation: double modules with Czech universities, reciprocal recognition of credits, participation in Horizon Europe consortia, implementation of English-taught tracks, and joint publications.

Educational tools and examples of modules:

- *Farm-to-Fork Engineering* is assessment of the resource footprint (water, soil, energy) of technological solutions, organic practices, and supply chain traceability.
- *Digital Ag Systems* are sensor networks, telemetry, satellite data, analytics, and visualisation.
- *Mechatronics for Agro* is robotic manipulators, drive systems, control and safety.
- *Sustainable Processing* is energy-efficient drying, heat and mass transfer, recuperation, and closed water cycles.

- *Data-Driven Maintenance* is predictive diagnostics, digital twins, vibration and load analysis.

At the level of higher education institutions: improved quality of engineering training, international transparency of qualifications, a higher proportion of students engaged in R&D and start-ups, and expanded partnerships and mobility. At the level of enterprises: reduced energy consumption and downtime, greater repeatability of quality, improved environmental performance of products, and enhanced transparency and traceability. At the level of the economy: a shift to higher added-value products, strengthened positions in EU markets, and compliance with ESG requirements without loss of productivity.

Within university-industry partnerships, a joint precision agriculture laboratory is established with GIS/drone modules, machine telemetry, agrochemical sensors, and training plots. Students undertake engineering tasks: simulated and real task maps for input application, equipment control algorithms, scenarios for fuel and pesticide savings, and LCA evaluation of technological maps. The results are implemented with partners and serve as the basis for joint publications, patent applications, and commercialisation.

Normative and policy benchmarks:

- the European Green Deal; the EU *Farm to Fork Strategy*; the EQF;
- the National Qualifications Framework of Ukraine (Resolution of the Cabinet of Ministers No. 1341 and subsequent amendments);
- the Licensing Conditions for the Provision of Educational Activity (Resolution of the Cabinet of Ministers No. 1187);
- the Laws of Ukraine *On Education*, *On Higher Education*, *On Innovation Activity*;
- the EU-Ukraine Association Agreement;
- the *Strategy for the Development of Export of Agricultural, Food and Processing Industry Products of Ukraine until 2026*.

Quality, Accreditation, and Monitoring Mechanisms. For the sustainable implementation of changes, it is necessary to synchronise internal quality assurance systems with external accreditation procedures. A multi-level monitoring framework is proposed:

- course level is assessment rubrics aligned with LOs, mandatory portfolios and artefacts (code, models, test benches, LCA reports);
- programme level is independent stakeholder reviews, audits of practices and R&D sprints, verification of equipment relevance;
- university level is annual public analytical reports on the achievement of indicators, open data on employment and career progression.

Such approaches are consistent with the requirements of transparency and accountability embedded in European standards and the norms of Ukrainian legislation.

The "teacher-mentor" model presupposes the integration of pedagogical expertise, research competences, and the ability to manage engineering projects. An annual professional development plan is recommended: internships at European universities and enterprises, participation in grant-funded projects, development of authorial courses, micro-qualifications in production network cybersecurity, occupational safety, and eco-design. For practising engineers engaged in teaching, flexible contracts, joint supervision of projects, co-authorship of publications, and a system of recognition of results within company reports are envisaged.

Basic Infrastructure: computer laboratories, CAE/CFD/CAD, measurement complexes, test benches, unmanned platforms, and data servers. Funding is ensured through a combination of state and grant resources (including Horizon Europe), industrial contracts, and co-financing mechanisms with local communities and donors. A mechanism of service contracts is being introduced: laboratories provide enterprises with services in testing, metrology, and digital auditing, thereby generating resources for equipment renewal and the support of scholarship programmes.

In the context of the growing role of cyber-physical systems, issues of cybersecurity in production processes, protection of telemetry data, and safeguarding of trade secrets are becoming increasingly pertinent. Educational programmes must incorporate modules on IIoT threats and protection, secure integration of PLC/SCADA, access policies, vulnerability management, and incident response. The ethical component encompasses the responsible use of data, prevention of "greenwashing", transparent declaration of environmental indicators, and accurate risk assessment.

Example of a Curriculum Structure (fragment):

- Semesters 1–2: sustainable and digital engineering, mechatronics, GIS/drones, R&D sprint.
- Semesters 3–4: PLC/SCADA, CAD/CAM/PLM, LCA, Farm-to-Fork Engineering module, internship and thesis project.

Impact Assessment (KPIs). Educational: proportion of courses with a project component (>70%), percentage of students who have completed prototypes or software (>40%), number of micro-qualifications per student (≥2/year). Research: joint university-enterprise publications, intellectual property applications, participation in international projects. Production: reduction in specific energy/pesticide consumption, decreased downtime, increased productivity. Environmental: reduction of emissions and waste, introduction of closed-loop water practices, share of organic plots in case studies.

The risk of resource insufficiency is mitigated by phased procurement and service contracts with businesses; staff-related risk—through mentoring programmes and dual "teacher–engineer" positions; regulatory risk—through systemic dialogue with the Ministry of Education and Science and the National Agency for Higher Education Quality Assurance, as well as pilot accreditations; institutional risk—through the formalisation of partnerships and a transparent intellectual property allocation system. A reserve of time is provided for equipment adaptation and the integration of safety protocols.

Integrated dual trajectories are expected to form local innovation ecosystems:

- universities become centres of expertise,
- the proportion of processing and precision agriculture services increases,
- community competitiveness is strengthened.

Discussion

In the conducted study, the regulatory frameworks of the EU and Ukraine, the educational models of the Czech Republic, as well as the possibilities of their implementation in the Ukrainian context were analysed. The findings indicate that the transformation of engineering education is impossible without a comprehensive revision of existing approaches to the

organisation of the educational process. Foremost is the integration of practice-oriented learning methods, close cooperation between universities and business, and a focus on competences defined by the European Qualifications Framework.

At the same time, questions arise concerning the resource and staffing provision of the proposed changes. The Czech experience demonstrates the effectiveness of short industrial sprints and joint laboratories; however, for Ukraine, challenges remain in financing equipment, training a new type of lecturer, and establishing mechanisms for the protection of intellectual property. Furthermore, the integration of digital technologies into the educational process (IoT, SCADA, digital twins) requires not only technical infrastructure but also the cultivation of a culture of data use, their protection, and an ethical attitude towards outcomes.

The issue of balancing academic training and industrial practice is also subject to debate. On the one hand, universities must prepare specialists with a broad worldview and fundamental knowledge; on the other hand, the labour market demands "quick solutions" and readiness to work with specific equipment and technologies. The dual model of "university—R&D—production" may serve as a compromise, but its scaling requires regulatory flexibility and a sustained dialogue among all participants in the educational process.

Thus, the proposed approaches open new opportunities for the development of Ukrainian engineering education, yet they necessitate further discussions and clarifications. In particular, it is important to address the issues of resource support, the integration of micro-credentials, the assessment of learning outcomes, and the role of international partnerships. Solving these problems will make it possible to move from declarations to real practices and ensure the training of engineers capable of working within the conditions of the European market and global challenges.

Conclusion

Modern European policy in sustainability and innovation is shaping a fundamentally new profile of the engineer. This is no longer merely a professional capable of producing technical drawings or maintaining systems. Today, the engineer is regarded as a highly qualified specialist able to design, model and validate technological solutions, taking into account the entire product life cycle, its digital footprint, compliance with environmental requirements and regulatory standards. Within such a paradigm, key significance is attached to competences that integrate technical knowledge with managerial, environmental and digital skills.

The example of the Czech Republic demonstrates that the most effective models of training are those which combine academic education with real industrial practice. Project-based learning, the establishment of joint university-business laboratories, and the organisation of short but intensive R&D sprints focused on the needs of enterprises make it possible to update curricula rapidly and to prepare engineers equipped with "new wave" skills. Owing to this practice-oriented model, student projects are more readily transformed into prototypes, start-ups or fully-fledged innovative solutions, while graduates integrate more easily into the labour market.

For Ukraine, this experience is of exceptional relevance. The national legal and regulatory framework already contains the instruments required to scale up such approaches. In particular, the NQF, harmonised with the EQF, ensures the "readability" of learning outcomes for

European employers. Licensing conditions, the Laws of Ukraine *On Education*, *On Higher Education*, *On Innovation Activity*, as well as the provisions of the EU-Ukraine Association Agreement, establish the legal framework for the integration of dual programmes, international projects, and educational-research partnerships.

The successful implementation of European practices requires a systemic approach. First and foremost, curricula need to be redesigned with a focus on developing transversal competences in sustainable engineering, digital engineering, product life cycle management, innovative entrepreneurship, and the safety of production processes. Special attention should be devoted to the integration of modules on intelligent technologies: sensor systems, drones, satellite monitoring, digital twins, PLC/SCADA platforms, as well as methods of machine learning.

A crucial factor is the establishment of a sustainable dialogue between universities, business and the state. Only within a partnership format can the relevance of educational outcomes, access to modern equipment, opportunities for placements, and project tasks aligned with real industrial needs be guaranteed. Equally important is internationalisation: joint programmes with EU universities, participation in Horizon Europe consortia, mutual recognition of credits, international publications and dual degree schemes create favourable conditions for integrating Ukrainian engineers into the global market.

It is also essential to emphasise the importance of cultivating a culture of measurable outcomes. Contemporary approaches require not only the declaration of aims or competences, but also their clear operationalisation through indicators: the number of prototypes, start-ups, joint publications, implemented case studies, reductions in energy consumption, and ecological impact. Precisely this culture of evidence and transparency underpins stakeholder trust and enhances the effectiveness of educational and research systems.

Thus, the key conditions for success may be outlined as follows: the renewal of curricula "for the tasks of the future"; continuous dialogue with business and industrial partners; internationalisation through educational and scientific consortia; and the formation of a culture of measurability and accountability for outcomes. The implementation of these conditions will enable Ukraine to prepare "new wave" engineers-specialists who not only possess advanced technical knowledge, but are also capable of responding to global challenges related to sustainability, digitalisation and innovation.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

A Digital Europe Programme 2021–2027. (2021). European Commission. https://digital-strategy.ec.europa.eu

Association Agreement between Ukraine and the European Union, the European Atomic Energy Community and their Member States. (2014). Law of Ukraine No. 1678–VII dated September 16, 2014. (In Ukr.)

Farm to Fork Strategy: For a Fair, Healthy and Environmentally-Friendly Food System. (2020). European Commission. https://food.ec.europa.eu

On Approval of the National Qualifications Framework. (2011). Resolution of the Cabinet of Ministers of Ukraine No. 1341 dated November 23, 2011. (In Ukr.)
On Education. (2017). Law of Ukraine No. 2145–VIII dated September 5, 2017. (In Ukr.)
On Higher Education. (2014). Law of Ukraine No. 1556–VII dated July 1, 2014. (In Ukr.)
On Innovation Activity. (2002). Law of Ukraine No. 40–IV dated July 4, 2002. (In Ukr.)
On Licensing Conditions for Educational Activities. (2015). Resolution of the Cabinet of Ministers of Ukraine No. № 1187 dated December 30, 2015. (In Ukr.)
On the European Qualifications Framework for lifelong learning (EQF). (2017). Recommendation of the European Parliament and of the Council.
Strategy for the Development of Agricultural, Food and Processing Industry Exports of Ukraine until 2026. (2019). Resolution of the Cabinet of Ministers of Ukraine No. 588-p dated July 10, 2019. (In Ukr.)
The European Green Deal. (2019). European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640

Olena O. Trukhanska [a][17]

Investigation of the Operation of the Electromechanical System of an Autonomous Photovoltaic Pumping Station [13]

Abstract: The article analyzes the structure and operation of a photovoltaic pumping station. The key components of the system, such as solar panels, electronic controllers, electromechanical pumps, and energy storage, were studied. In particular, various methods of maximising energy output from solar panels and optimising the efficiency of pumping systems were investigated. The results of the study showed that the efficient operation of a photovoltaic pumping station depends on the precise balancing of electromechanical components, optimal use of solar energy, and efficient management of electronic systems. Recommendations for improving the efficiency and reliability of the system have been put forward. In the course of the study, it was established that one of the key factors for the effective operation of a photovoltaic pumping station is the proper selection of solar panel type and the optimisation of their placement to ensure maximum solar energy conversion. The issue of storing surplus energy was also analysed to maintain stable system performance during periods of reduced solar activity. In addition, the research involved modelling and experimental studies of various operating modes of the pumping station, including changes in load and fluctuations in solar radiation. This made it possible to obtain valuable results regarding the dynamic characteristics of the system and its compliance with the specified technical parameters. An important part of the study was the evaluation of the efficiency and economic feasibility of using a photovoltaic pumping station compared to traditional energy sources for water supply. It was demonstrated that in certain cases the use of solar energy may be not only more environmentally friendly, but also economically advantageous. Overall, the results of this work have significant practical value for developing sustainable energy and the broader application of renewable energy sources. The study of an autonomous photovoltaic pumping station contributes to a deeper understanding of the technological, economic, and environmental aspects of such systems. In conclusion, this scientific work provides greater insight into the principles of operation of autonomous photovoltaic pumping systems and can serve as a basis for further research in renewable energy.

Keywords: photovoltaic energy, autonomous pumping station, electromechanical system, solar panels, pumping systems.

Abbreviations:

AES is power supply systems,

PV is autonomous photovoltaic,

RES is renewable energy sources.

Introduction

To irrigate crops, pump water for domestic use, and water livestock, pumping systems with an appropriate power source are needed. However, in rural areas, energy sources may be far from water sources, which increases the cost of building infrastructure (*Kondalkar et al., 2019*; *Razzaq et al., 2019*; *Kupchuk et al., 2023*; *Tsurkan et al., 2022*; *Puyu et al., 2021*). Now there are many sources of electricity based on internal combustion engines that can be used for autonomous water pumping systems. They are portable, easy to install, and independent of

[a] Candidate of Engineering Science (Ph.D.), Associate Professor, Department of Agro-Engineering and Technical Service, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.

infrastructure. However, these systems require maintenance and fuel, and have a negative impact on the environment. The use of renewable energy is an attractive option for autonomous water supply systems in rural and desert areas.

In particular, generating electricity using photovoltaic cells looks very attractive for water supply systems. Photovoltaic systems have many advantages, such as ease of installation, low infrastructure requirements, stability, and quietness. They can be used even in remote locations and require little maintenance.

The use of autonomous photovoltaic water pumping systems should help improve life in remote areas and preserve the environment (*Razzaq et al., 2019*; *Mazur et al., 2021*; *Semenov et al., 2021*; *Semenov et al., 2019b*; *Hraniak et al, 2022*; *Honcharuk et al., 2023*; *Lohosha et al., 2023*).

The purpose of this research work is to create an independent photovoltaic pumping system. The first stage includes the development of the project concept, determination of key control, regulatory and signal parameters. Further development includes the design of the PV power plant as a whole, the selection of appropriate control and regulatory devices and tools that provide control over the work process, and the study of the functioning of the electromechanical system. Automation of a PV power plant will have a positive impact on working conditions, energy and material conservation, and increase production efficiency.

Literature Review

The development of PV pumping stations is grounded in the broader context of renewable energy integration into electromechanical systems. The global shift toward sustainable technologies has intensified research on energy efficiency, system automation, and the reliability of photovoltaic installations for water supply and irrigation in rural or isolated regions. Studies have emphasised the necessity of combining engineering optimisation with environmental and economic considerations to ensure sustainable operation (*Razzaq et al., 2019*; *Puyu et al., 2021*; *Honcharuk et al., 2023*).

A fundamental direction of recent research concerns the optimisation of PV panels and their interaction with electric drive systems. Kondalkar et al. (*2019*) and Kumar et al. (*2021*) analysed the parameters influencing sensor performance and power stability in electromechanical networks, demonstrating that humidity and insulation control significantly affect efficiency. Kupchuk et al. (*2023*) and Tsurkan et al. (*2022*) explored digital processing algorithms and adaptive communication systems, which enable more precise regulation of PV-driven systems under changing environmental conditions. These findings are crucial for ensuring energy independence in autonomous water supply facilities.

Significant attention has been devoted to the automation and modelling of photovoltaic systems. Nazarova (*2020*) and Semenov et al. (*2020*) developed mathematical and computer models for electromechanical devices that incorporate feedback and nonlinear dependencies to simulate transient processes under fluctuating voltage conditions. Similarly, Hrabko et al. (*2024*) investigated frequency-controlled asynchronous drives and diagnostic methods using FPGA systems, which facilitate the detection of failures and enhance operational reliability. These studies collectively demonstrate the essential role of modelling and diagnostics in optimising the performance of photovoltaic pumping stations.

The technical progress in renewable energy systems is also associated with innovations in materials and sensor technologies. Hraniak et al. (*2022*) and Krivoruchko et al. (*2012*) developed models of dielectric and humidity sensors improving the precision of system monitoring. These sensors are integrated into PV systems to measure critical parameters such as temperature, voltage, and current fluctuations, ensuring the stable operation of photovoltaic modules. Additionally, Lohosha et al. (*2023*) highlighted the importance of integrating internal management and marketing mechanisms in renewable energy production systems, underlining the necessity of coordination between technological and organisational components for sustainable functioning.

Further studies address the electromechanical and control aspects of energy conversion. Semenov et al. (*2019a*; *2019b*; *2021*) proposed models of deterministic chaos oscillators and non-standard microwave systems that improve efficiency through the optimisation of self-oscillatory parameters. Such research broadens the theoretical understanding of nonlinear energy systems and provides methodological bases for future photovoltaic applications. Voznyak et al. (*2023*) and Spirin et al. (*2023*) advanced image recognition and analytical algorithms applicable in control and diagnostic systems for renewable energy installations, improving the precision of automated monitoring and predictive maintenance.

The economic and ecological dimensions of renewable technologies are equally important. Mazur et al. (*2021*) and Vasilevskyi et al. (*2023*) demonstrated that digital transformation and precision measurement technologies reduce energy losses and enhance sustainability, particularly in agricultural and rural settings. Studies by Wallin (*2000*) and Gunko et al. (*2021*) complemented this approach with turbulence and airflow models applicable to energy transfer optimisation. Collectively, these contributions form the scientific foundation for designing efficient photovoltaic pumping systems that balance environmental protection with technical feasibility.

Thus, the existing body of research substantiates that the effective operation of photovoltaic pumping stations depends on the accurate modelling of electromechanical parameters, the integration of smart diagnostics, and the sustainable management of energy flows. The combination of advanced materials, digital control systems, and renewable energy technologies creates a coherent interdisciplinary framework supporting the transition toward autonomous, environmentally responsible power systems (*Kupchuk et al., 2023*; *Semenov et al., 2020*; *Hrabko et al., 2024*).

Materials and Methods

Overview of Automated Power Supply Systems

Renewable energy sources are becoming more and more popular in the world, as they allow you to obtain energy without the use of natural fuels and have a minimal negative impact on the environment. Among these sources, solar, wind, hydropower, biofuels and others stand out. One of the areas of their use is automated power supply systems, which provide the necessary energy for various needs, using renewable sources.

Automated energy supply systems are used for residential buildings, as well as for commercial and industrial facilities. One of the main advantages of such systems is their

independence from the centralized power supply network. They can operate in remote and inaccessible areas where connection to the general network is impractical or impossible.

The main component of automated systems is the use of solar panels or wind turbines to generate electricity. Solar panels convert solar radiation into electricity through the photovoltaic effect, while wind turbines use the kinetic energy of the wind to generate electricity. These sources can operate in different conditions and provide a constant flow of energy.

For the efficient operation of such systems, it is necessary to use specialized controllers and control algorithms. They allow you to track energy production and consumption, optimize system operation depending on external conditions and user needs.

Such systems have a number of advantages, including reduced energy costs, reduced carbon emissions, increased reliability and resilience to outages from the centralized network. However, they also have their challenges, including a lack of energy at night or in light winds, as well as the need to manage and maintain the system.

The growing interest in automated energy supply systems encourages further research and development in this area. Understanding the principles of their operation and improving control algorithms can contribute to the wider and more efficient use of renewable energy sources, which in turn will help to conserve resources and reduce the negative impact on the environment (*Lohosha et al., 2023*; *Semenov et al., 2019a*; *Semenov et al., 2020*; *Spirin et al., 2023*; *Paziuk et al., 2021*; *Gunko et al., 2021*; *Voznyak et al., 2023*; *Krivoruchko et al., 2012*; *Wallin, 2000*).

For ensure reliable and high-quality power supply to demanding consumers, autonomous (uninterrupted) AES have been used, which include several sources of electricity, such as main, backup and emergency sources. Contributing to this, the possibilities of using RES are coming, since the limited resources of organic fuels and the negative environmental impact of traditional methods of energy production make it relevant.

One of these approaches, the photovoltaic power supply system, includes components that interact with each other to ensure efficient delivery of for electricity from small devices to the overall load. Power supply systems are divided into three categories: grid-connected, stand-alone, and hybrid, including sources such as photovoltaic panels, diesel generators, and wind turbines. Both systems can use storage, such as batteries or supercapacitors, for nighttime or times of insufficient sunlight.

Photovoltaic panels in autonomous systems directly power the load, independent of the utility grid. Stand-alone systems are particularly cost-effective for introducing photovoltaic energy, especially in rural areas with intense solar radiation and limited access to the grid. This can be used for communication systems, water supply, navigation, emergency services, or military facilities that require an additional source of energy.

Stand-alone systems have drawbacks, such as low power storage, batteries with limited capacity, which can lead to the loss of stored energy. Additionally, they have important features such as the need for storage nighttime hours when there is no sunlight, and adjusting the operating power according to the load (*Kupchuk et al., 2023*; *Yaropud et al., 2022*; *Polievoda et al., 2022*; *Vasilevskyi et al., 2023*).

Research and Development of a Block Diagram of an Electric Drive System

Research and development of the structural diagram of the electric drive system is a key aspect in the process of improving electrical engineering systems. This topic focuses on the analysis and determination of optimal components and connections that provide efficient and reliable energy transfer in the system. The research covers the study of various options for structural solutions to meet the needs of the electric drive, and the development includes the creation of conceptual and practical models for implementing the selected structural solutions. An important aspect is ensuring optimal coordination between the various components of the electric drive system to achieve maximum performance and efficiency. As a result of research and development of the structural diagram of the electric drive system, it is possible to improve the quality and reliability of electrical systems in various fields of application, from industry to household devices.

Photopanel is an interface capable of converting light into electrical energy. Modeling this device requires weather data such as irradiance and temperature as input variables. Output parameters can be current, voltage or power. Any change in the input values leads to a change in the results, so it is important to use an adequate model for the photopanel. In this model, the influence of irradiation and temperature on the parameters of the photovoltaic module should be considered. One model is based on using a diode model with series and parallel resistors for more accurate results.

The more accurate the structural model, the more unknown parameters it contains. Often manufacturers' specifications provide insufficient information about parameters that depend on weather conditions. Thus, to establish a mathematical model of a PV panel it is necessary to make assumptions about the physical nature of its behavior (*Figure 1*).

The main goal of the model under study is to achieve maximum power close to the experimental values at any time. The external characteristic of a PV panel I(V) is a nonlinear equation with many parameters that can be classified as design parameters, known constants, and those that need to be calculated. In some cases, simplified methods are used, where some unknown parameters are treated as constants. Such assumptions help reduce the complexity of modeling. However, there are also researchers who consider the values of all internal parameters for more accurate results (*Semenov et al., 2019a*; *Semenov et al., 2020*; *Spirin et al., 2023*; *Paziuk et al., 2021*; *Gunko et al., 2021*).

In general, PV panel is a significant component in renewable energy systems, and developing appropriate models helps to achieve greater efficiency and accuracy in its operation.

Considering the power value calculated above, we will select the AXM144-9-166-470 PV panel with the technical characteristics shown in Table 1 (*See Appendix*).

Two experiments were conducted using this model. Namely, the study of dynamic and static characteristics at the nominal and reduced input voltage of the PV panel. In the following two experiments, the load torque on the pump motor shaft is reduced by 10 Nm per 1 s. The pump in this model is represented by the following equation (21):

$$K = \frac{M_n}{\omega_n^2} = \frac{72}{152.62^2} = 0.00292.$$

Transients' Processes at Rated Input Voltage

The function scheme diagram of the soft start device is shown in Figure 2 (*See Appendix*).

Having modeled the system, graphs of transient processes were obtained, which clearly show the functioning of the interconnected components of the system. The experiment was carried out at a photopanel output voltage of 490 V (*Tsurkan et al., 2017*; *Hrabko et al., 2024*).

As a result of system modeling at the nominal input voltage transient processes were obtained, which can be seen in Figure 2 and Figure 3 (*See Appendix*). In the first case the voltage during the load-on phase of the motor gradually increases to the nominal value of 380 V. As the load changes on both the rotor and stator, the currents become smaller and approach the motor's rated values, as seen in Figure 2. Looking at Figure 3, it can be observed that the motor reaches the set speed in 1.1 seconds. The torque on the motor shaft also approaches the rated value (*Yaropud et al., 2022*; *Nazarova, 2020*).

Thus, at the nominal input voltage this system demonstrated performance that meets the expected result. This confirms that the system under consideration is able to operate stably and efficiently under rated conditions.

Transients at Input Voltage Reduction

When analyzing the transient processes when the input voltage in the system is reduced interesting dependencies and characteristics were found that can be illustrated by figures and analyzed in detail.

Reducing the input voltage led to a change in the system dynamics. The transient process showed that as the input voltage decreased, the voltage at the supply output began to decrease. In the first moments, a significant voltage drop was observed, indicating that the system reacted to this decrease quite quickly. Then, according to the graph, the output voltage stabilized at a certain value, showing that the system had reached a new state of equilibrium.

Observing the change in the currents in the system, it can be noted that they also decreased in response to the reduced voltage. Initially, there was a short-term current peak, which was due to the system's reaction to the sudden change in conditions. However, later the currents began to decrease and, similarly to the voltage, stabilized at the new value.

Changes in transients also affected the system's efficiency characteristics. It turned out that when the input voltage was reduced, the system efficiency initially decreased slightly. However, later, when the system reached a new state of equilibrium, the efficiency stabilized at a certain level.

The functional diagram of the soft start device is shown in the Figure 4 (*See Appendix*).

Since in real-world conditions, systems that use PV panels can be subject to changes in weather conditions, namely temperature and irradiation, the output voltage can also change. As an example, in the experiment, the output voltage of the PV panel will be reduced by 100 V (*Figure 4*; *Figure 5*).

Having considered the transients obtained as a result of the second experiment it is worth noting that the power decreased due to the lower input voltage. This resulted in changes in currents and torque on the motor shaft.

Discussion

The transient analysis confirms that the reduction of the input voltage has a significant impact on the system operation. The displayed changes in voltage, currents, and efficiency show how the system adapts to the new conditions and ensures stable operation. A detailed analysis of these processes is an important step in improving and optimizing the operation of the electric drive system.

In parallel with the analysis of voltage and current dynamics, it is worth considering the impact of input voltage reduction on other system parameters.

In particular, an important aspect is the change in the speed of the system's response to voltage reduction. From the graphs, you can see that there is a certain delay before the system begins to adapt to new conditions. This can be important in assessing the system's responsiveness to unpredictable changes in power conditions.

In addition, transients can affect the mechanical stability of the system. A decrease in the input voltage can cause a change in the torque and speed of the system, which in turn can affect its stability and performance.

It is also important to note that lowering the input voltage can lead to increased stress on system elements such as the motor. This can affect how long they last, wear and tear, and the overall reliability of the system.

Transient analysis at input voltage reduction can also help identify possible limitations and risks in system operation. For example, if there is a very slow response to voltage changes, this may indicate problems with the reactivity or insufficient power of the system elements.

As a result, the analysis of transients during input voltage reduction provides a lot of important information about the system operation under conditions of changing input parameters. This analysis is key to ensuring the stability, efficiency, and reliability of the drive system under various conditions.

Conclusion

This study considered aspects of creating an autonomous water supply source based on a photovoltaic renewable power source that works in conjunction with an electric drive based on an induction motor with an autonomous inverter. Taking into consideration the experiments and analysis the following conclusions were obtained:

According to the results of a detailed analysis of scientific and technical literature, the efficiency of a PV power station can be significantly improved by using MPPT algorithms to maximize power extraction from a PV panel. This strategy helps to ensure optimal operation of the PV system.

It has been demonstrated that the combination of a PV panel with an electric drive for panel rotation can be characterized by increased power generation. The correct angle of panel rotation helps to maximize irradiation and temperature parameters, which have a key impact on power generation.

Different methods of electric drive control are investigated, and it is found that in the case of interaction of an induction motor with a pump, the most effective is the use of frequency control. This strategy allows to achieve an optimal ratio between the generated energy and the demand.

Modelling of the autonomous water supply system in MATLAB/Simulink confirmed the compliance of the developed system with the specified requirements. The transient graphs indicate the stability and adequacy of the system's operation in real-world conditions.

Thus, the study indicates that the implementation of an autonomous water supply system based on a photovoltaic power source and an induction drive is a promising and effective approach to ensure reliable and sustainable water supply in remote regions.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Gunko, I., Babyn, I, Aliiev, E., Yaropud, V., & Hrytsun, A. (2021). Research into operating modes of the air injector of the milking parlor flushing system. *UPB Scientific bulletin, Series D: Mechanical Engineering*, *83*(2), 297–310.

Honcharuk, I., Tokarchuk, D., Gontaruk, Y., & Hreshchuk, H. (2023). Bioenergy recycling of household solid waste as a direction for ensuring sustainable development of rural areas. *Polityka Energetyczna – Energy Policy Journal*, *26*(1), 23–42. https://doi.org/10.33223/epj/161467

Hrabko, V., Protsenko, D., Bartetskyi, A., Gunko, I., Shvets, L., Chmykh, K., Trukhanska, O., & Ryaboshapka, V. (2024). System diagnostics of braking circuits of frequency-controlled asynchronous electric drives converters using FPGA. *Przeglad Elektrotechniczny*, *100*(5), 153–157. https://doi.org/10.15199/48.2024.05.28

Hraniak, V. F., Matviychuk, V. A., & Kupchuk, I. M. (2022). Mathematical model and practical implementation of transformer oil humidity sensor. *Electronics*, *26*(1), 3–8. https://doi.org/10.53314/ELS2226003H

Kondalkar, V. V., Ryu, G., Lee, Y., & Lee, K. (2019). Development of highly sensitive and stable humidity sensor for real-time monitoring of dissolved moisture in transformer-insulating oil. *Sensors and Actuators B: Chemical*, *286*, 377–385.

Krivoruchko, J. S., Lerman, L. B., & Skoda, N. G. (2012). Multicomponent heterogeneous systems; effective dielectric constant and absorption. *Bulletin of NTU "KhPI"*, *66*, 167–173.

Kumar, S., Raina, K. K., & Islam, T. (2021). Anodic aluminium oxide-based humidity sensor for online moisture monitoring of power transformer. *Sensors and Actuators B: Chemical*, *329*, 128908.

Kupchuk, I., Voznyak, O., Burlaka, S., Polievoda, Y., Vovk, V., Telekalo, N., & Hontaruk, Y. (2023). Information transfer with adaptation to the parameters of the communication channel. *Przeglad elektrotechniczny*, *99*(3), 194–199. https://doi.org/10.15199/48.2023.03.34

Lohosha, R., Prylutskyi, A., Pronko, L., & Kolesnyk, T. (2023). Organization of the System of Internal Marketing and Marketing of Interaction of Agricultural Enterprises for the Production of Biodiesel Based on Value Chain Analysis. *Journal of Environmental Management and Tourism*, *67*(3), 823–841. https://doi.org/10.14505/ jemt.v14.3(67).21

Mazur, V., Tkachuk, O., Pantsyreva, H., & Demchuk, O. (2021). Quality of pea seeds and agroecological condition of soil when using structured water. *Scientific Horizons*, *24*(7), 53–60.

Nazarova, O. (2020). Computer Modeling of Multi-Mass Electromechanical Systems. *The Third International Workshop on Computer Modeling and Intelligent Systems (CMIS-2020)*, *2608*, 489–498.

Paziuk, V., Petrova, Z., Tokarchuk, O., & Polievoda, Y. (2021). Special aspects of soybean drying with high seedling vigor. *Scientific bulletin, Series D: Mechanical Engineering*, *83*(2), 327–336.

Polievoda, Y., Kupchuk, I., Hontaruk, Y., Furman, I., & Mytko, M. (2022). Method for determining homogeneity of fine dispersed mixtures based on the software analysis of photo cross-cut of the sample. *Przeglad elektrotechniczny*, 98(11), 109–113. https://doi.org/10.15199/48.2022.11.20

Puyu, V., Bakhmat, M., Pantsyreva, H., Khmelianchyshyn, Y., Stepanchenko, V., & Bakhmat, O. (2021). Social-and-Ecological Aspects of Forage Production Reform in Ukraine in the Early 21st Century. *European Journal of Sustainable Development*, *10*(1), 221–228.

Razzaq, A., Zainuddin, H., Hanaffi, F., & Chyad, R. M. (2019). Transformer oil diagnostic by using an optical fibre system: a review. *IET Science, Measurement and Technology*, *13*(5), 615–621.

Semenov, A. A., Baraban, S. V., Semenova, O. O., Voznyak, O. M., Vydmysh, A. A., & Yaroshenko, L. V. (2019a). Statistical Express Control of the Peak Values of the Differential-Thermal Analysis of Solid Materials. *Solid State Phenomena*, *291*, 28–41. https://doi.org/10.4028/ www.scientific.net/SSP.291.28

Semenov, A. O., Voznyak, O. M., Osadchuk, O. V., Klimek, J., & Orazalieva, S. (2019b). Development of a non-standard system of microwave quadripoles parameters. *Proceedings of SPIE – The International Society for Optical Engineering*, *11176*, 111765N. http://dx.doi.org/10.1117/12.2536704

Semenov, A., Semenova, O., Rudyk, A., Voznyak, O., Pinaiev, B., & Kulias, R. (2020). Mathematical Model of Microwave Devices on Resonant Tunneling Diodes for Practical Application in Radar and Electronic Systems. *2020 IEEE Ukrainian Microwave Week, UkrMW 2020 – Proceedings*, 272–277. https://doi.org/10.1109/ UkrMW49653.2020.9252673

Semenov, A., Osadchuk, O., Semenova, O., Voznyak, O., Rudyk, A., & Koval, K. (2021). Research of dynamic processes in the deterministic chaos oscillator based on the colpitts scheme and optimization of its self-oscillatory system parameters. *Lecture Notes on Data Engineering and Communications Technologies*, *48*, 181–205 http://dx.doi.org/10.1007/978-3-030-43070-2_10

Spirin, A., Borysiuk, D., Tsurkan, O., Tverdokhlib, I., Trukhanska, O., & Veselovska, N. (2023). Research of the method of calculating the area of a binary image. *Przeglad Elektrotechniczny*, *99*(10), 125–128. https://doi.org/10.15199/48.2023.10.24

Tsurkan, O. V., Gerasimov, O. O., Polyevoda, Y. A., Tverdokhlib, I. V., Rimar, T. I., & Stanislavchuk, O. V. (2017). Kinetic features of vibrating and filtration dewatering of fresh-peeled pumpkin seeds. *INMATEH – Agricultural Engineering*, *52*, 2, 69–76.

Tsurkan, O., Kupchuk, I., Polievoda, Y., Wozniak, O., Hontaruk, Y., & Prysiazhniuk, Y. (2022). Digital processing of one-dimensional signals based on the median filtering algorithm. *Przegląd elektrotechniczny*, *98*(11), 51–56. https://doi.org/10.15199/48.2022.11.08

Vasilevskyi, O. M., Sevastianov, V. M., Ovchynnykov, K. V., Didych, V. M., & Burlaka, S. A. (2023). Accuracy of potentiometric methods for measuring ion activity in solutions. *Proceedings of Seventh International Congress on Information and Communication Technology*, *1*, 181–190. https://doi.org/10.1007/978-981-19-1607-6_16

Voznyak, O., Polievoda, Yu., Kupchuk, I., Trukhanska, O., Shvets, L., & Zamrii, M. (2023). Development of object detection algorithm in halftone images. *Przeglad Elektrotechniczny*, *99*(11), 192–195. https://doi.org/10.15199/48.2023.11.33

Wallin, S. (2000). *Engineering turbulence modeling for CFD with a focus on explicit algebraic Reynoldce stress models* [Doctoral thesis]. Stockholm: Norsteds truckeri.

Yaropud, V., Honcharuk, I., Datsiuk, D., & Aliiev, E. (2022). The model for random packaging of small-seeded crops' seeds in the reservoir of selection seeder's sowing unit. *Agraarteadus*, *33*(1), 199–208. https://doi.org/10.15159/jas.22.08

Appendix

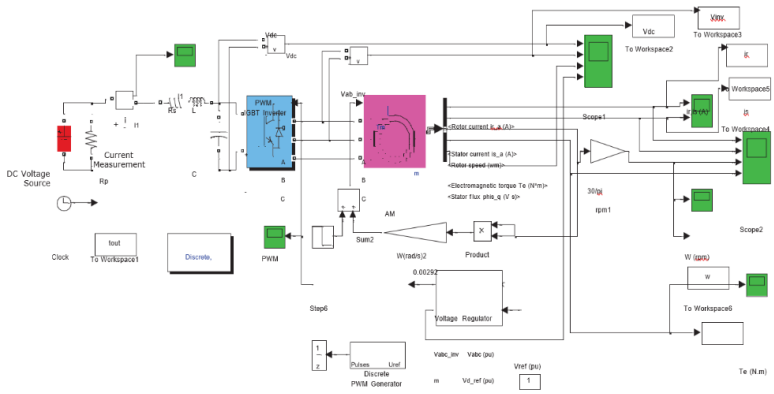

Figure 1. Scheme of the model of the studied system
Source: the author created the material based on (Kupchuk, 2023)

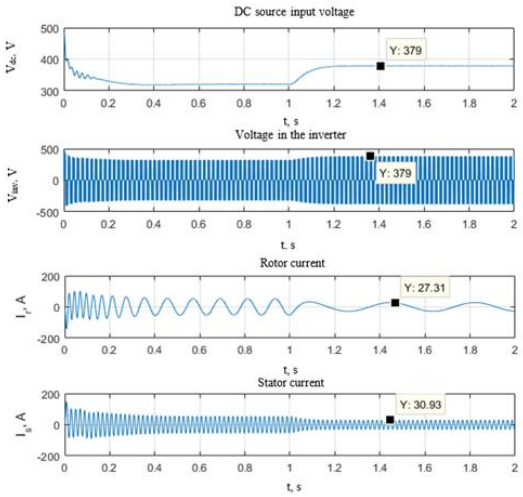

Figure 2. Figure 2. Motor transients at rated input voltage Udc = 490 V
Source: the author created the material based on (*Kupchuk, 2023*)

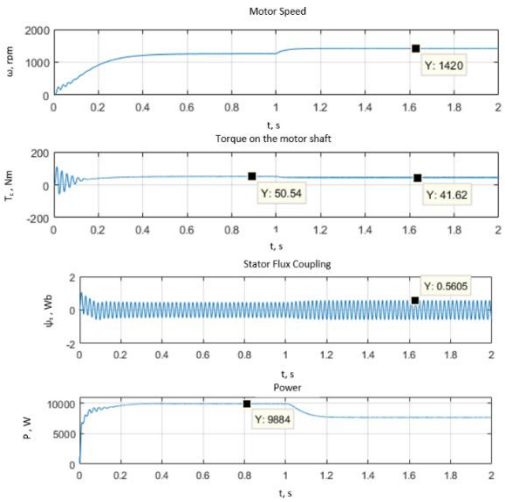

Figure 3. Motor transients at rated input voltage Udc = 490 V
Source: the author created the material based on (Kupchuk, 2023)

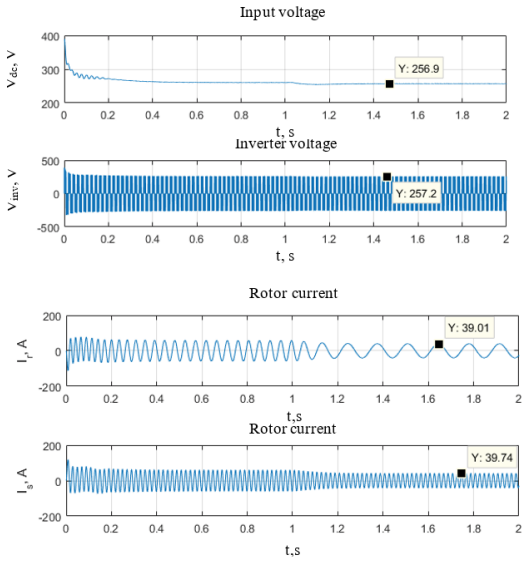

Figure 4. Motor transients at reduced input voltage Udc = 390 V

Source: the author created the material based on (Kupchuk, 2023)

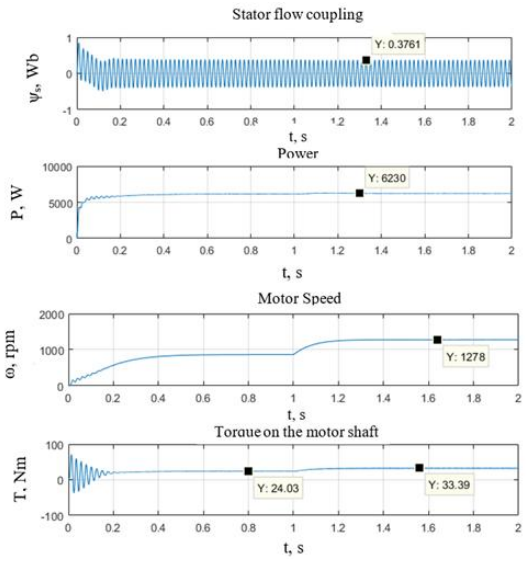

Figure 5. Motor transients at reduced input voltage Udc = 390 V

Source: the author created the material based on (Kupchuk, 2023)

Table 1. Technical characteristics of the AXM144-9-166-470 PV panel

Output power Pmax, W	470
Voltage Pmax Vm, V	41.44
Current Pmax Im, A	10.87
No-load voltage Voc, V	50.16
Short circuit current Isc, A	11.48
Temperature coefficient (Pmax), γ, % / 0C	-0.365
Temperature coefficient (Voc), βvoc, % / 0C	-0.285
Temperature coefficient (Isc), αisc, % / 0C	-0.055
Maximum system voltage Vmax, V	1000
Working temperature, 0C	-40~85

Source: the author compiled the material.

Ihor M. Kupchuk [a][18]

Modern Educational Trends in Agricultural Engineering: The Experience of the Czech Republic [14]

Abstract: The article provides a comprehensive analysis of current educational trends in training engineering specialists for agricultural machinery, using the Czech Republic as a case study. The object of the research is the system of higher technical education in agro-engineering in the Czech Republic, which covers areas such as mechanization, digital technologies, dual education, and industry partnerships. The aim of the study is to identify innovative educational approaches, quantitatively assess their effectiveness, and develop recommendations for possible adaptation in Ukraine. The methodological framework includes a comparative analysis of educational programs of leading Czech and Ukrainian universities, content analysis of scientific and reporting materials, statistical data processing (in particular, student and graduate numbers, salary levels), as well as expert evaluation of transfer prospects. The research draws on the work of Czech educators and international experts in engineering education. The results demonstrated that in the Czech Republic digital laboratories and simulation complexes are actively operating, dual education programs are being implemented, international mobility is widely supported, and close integration with industrial partners is ensured. Quantitative indicators are presented to illustrate the scale and effectiveness of these practices: Mendel University enrolls about 9,665 students in total, the average annual salary of an agro-engineer in the Czech Republic is approximately CZK 879,000, and the Agricultural Engineering program at the Czech University of Life Sciences is characterized by a clear practice-oriented structure. It is concluded that the Czech experience can serve as a valuable reference point for the modernization of Ukraine's system of agro-engineering education in the context of European integration.

Keywords: agricultural machinery engineering, agro-engineering, higher technical education, innovative educational approaches, dual education, digital technologies, industry cooperation.

Introduction

Developing agro-industrial production under conditions of global competition and Ukraine's integration into the European educational and scientific-technical space highlights the urgent need for high-quality training of engineering personnel in agricultural machinery manufacturing. Contemporary challenges associated with the digitalisation of production processes, the automation and robotisation of technological operations, the implementation of Industry 4.0, and the necessity of ensuring the sustainable development of the agricultural sector demand new competences from engineers. This involves not only a profound knowledge of agricultural mechanisation but also proficiency in digital tools, the ability to work within interdisciplinary integrated solutions, and a strong focus on energy efficiency and environmental sustainability in production.

An analysis of publications by international organisations and European experts (*Progressing toward…, 2022*; *Education at a glance…, 2020*) demonstrates that global trends in engineering education are moving towards enhanced practice orientation, the integration of dual education, the establishment of modern educational and research laboratories, active cooperation with industry, and the implementation of international programmes of academic mobility. Research

[a] Candidate of Technical Sciences (Ph.D.), Associate Professor, Department of Engineering Mechanics and Technological Processes in Agriculture, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.

conducted by Czech scholars (*Klus, 2021*) confirms that the combination of classical technical training with modern educational innovations ensures the high competitiveness of graduates in agro-engineering specialities.

The model of dual education, which combines theoretical learning with practical experience in enterprises, acquires particular significance in the training of engineers for the agro-industrial complex. In the Czech Republic, this practice has become systematic, contributing to higher employment rates among graduates and better alignment of their competences with the real needs of production. Moreover, the use of digital laboratories, simulation complexes, virtual and augmented reality technologies opens up new opportunities for modelling technological processes, optimising production systems, and developing students' professional skills in safe conditions.

At the same time, Ukraine faces a number of contradictions. On the one hand, agricultural machinery manufacturing is a strategically important industry, and the demand for highly qualified engineers is constantly increasing. On the other hand, the existing system of engineering education often fails to meet modern challenges: there is a limited number of dual programmes, insufficient integration of digital technologies into the educational process, and weak connections between universities and industry. This leads to a mismatch between the level of graduate training and the needs of the agricultural sector, which negatively affects the competitiveness of both individual enterprises and the industry as a whole.

Therefore, the scientific relevance of the problem lies in the need to study and adapt foreign experience, particularly that of the Czech Republic, which has successfully combined the traditions of a technical school with modern innovative educational approaches. The problem statement thus consists in identifying ways to modernise Ukraine's system of engineering education in agricultural machinery manufacturing, considering European practices that ensure a close interconnection between education, science, and production.

The study aims to identify and generalise the innovative educational approaches of the Czech Republic in the training of engineering personnel for agricultural machinery manufacturing, to provide a quantitative and qualitative assessment of their effectiveness, and to determine the possibilities for adapting this experience to modernise the Ukrainian system of agro-engineering education in the context of European integration processes.

According to the purpose of the study, the objectives are:

- conduct an analytical review of scientific publications and reports devoted to the development of engineering education in the Czech Republic and the European Union;
- perform a comparative analysis of educational programmes offered by Czech and Ukrainian universities in agro-engineering and agricultural machinery manufacturing;
- assess the role and effectiveness of key innovative practices—digital laboratories, dual education, international academic mobility, and partnerships with industry;
- analyse statistical data concerning the number of students and graduates, employment rates, and salary levels of agro-engineers in the Czech Republic;
- identify the prospects for transferring Czech experience and to outline practical recommendations for modernising Ukraine's system of engineering personnel training.

Methods

The methodological framework of the research is based on an integrated approach that combines several complementary methods.

A comparative analysis was employed to juxtapose the educational programmes of leading Czech universities (the Czech University of Life Sciences Prague (*Česká zemědělská univerzita v Praze, 2023*), Mendel University in Brno) with analogous programmes of Ukrainian higher education institutions specialising in agricultural engineering. This made it possible to identify similarities and differences in curriculum structures, course content, and the balance between theoretical and practical training.

Content analysis of scientific and reporting materials (publications by Czech educators, international experts, and analytical reports of the European Commission (*Education at a glance…, 2020*) and relevant ministries) enabled the systematisation of existing approaches to the modernisation of engineering education and the identification of key innovative practices.

Statistical analysis involved the processing of quantitative data, including the number of students and graduates in engineering specialisations, employment indicators, and the average salaries of agro-engineers in the Czech Republic. This allowed for a quantitative assessment of the effectiveness of educational approaches.

The expert evaluation method was used to determine the prospects for transferring Czech experience to Ukraine. The analysis incorporated insights from professionals in engineering education as well as practitioners from mechanical engineering enterprises.

The application of these methods in combination ensured a comprehensive understanding of innovative educational practices in the Czech Republic and made it possible to substantiate potential directions for their adaptation to the Ukrainian system of training engineering personnel in agricultural machinery.

Literature Review

The transformation of agricultural engineering education in the Czech Republic reflects broader European and global trends towards digitalisation, sustainability, and industry–academia collaboration. According to *Education Policy Strategy 2030+* (*2022*), the national framework prioritises innovation, practical competencies, and international mobility in alignment with EU objectives outlined in *Progressing toward the European Education Area* (*2022*). These policies have catalysed structural reforms in technical universities, particularly within Mendel University in Brno and the Czech University of Life Sciences in Prague (*Česká zemědělská univerzita v Praze*, 2023; *Annual Report…, 2022*), where dual education models integrate academic curricula with industrial placements.

The Czech experience demonstrates the significance of aligning higher technical education with labour market needs. Žalman and Dvořák (*2019*) emphasise the role of dual education as a means of bridging theoretical training and real-world application, while Klus (*2021*) identifies innovation-driven pedagogical approaches as essential for developing competencies relevant to Industry 4.0. The broader European context supports this orientation: the European Training Foundation (*Skills for agriculture…, 2021*) highlights the growing demand for adaptive skills in transition economies, and UNESCO (*Engineering…, 2021*) underscores the importance of engineering education in achieving the Sustainable Development Goals. Similarly, the *World*

Bank (*Transforming agricultural education…, 2020*) advocates reforming agricultural education in Eastern Europe to strengthen innovation ecosystems and digital capacities.

At the global level, Schwab's concept of the Fourth Industrial Revolution (*2017*) provides a theoretical framework for understanding the ongoing technological transformation of agricultural engineering. The integration of artificial intelligence, robotics, and precision technologies—described in *Digital Agriculture: Supporting Farmers in Transition* (*2020*)—is reshaping the competencies required of future engineers. OECD data (*Education at a Glance…, 2020*) confirm that countries investing in STEM and vocational innovation experience higher graduate employability and productivity outcomes. Within this framework, Czech graduates in agricultural engineering report competitive employment conditions and remuneration (*Agricultural engineer salary…, 2023*), indicating a strong linkage between educational quality and economic performance.

Furthermore, Erasmus+ mobility programmes (*Annual Report…, 2021*) have played a decisive role in internationalising Czech engineering education, promoting collaboration and the exchange of best practices within the European Higher Education Area. This aligns with the European Parliament's vision of a more resilient and sustainable agricultural sector (*Research for AGRI Committee, 2021*). Collectively, these studies and institutional reports demonstrate that the Czech model of agricultural engineering education—characterised by its dual approach, emphasis on sustainability, and integration of digital technologies—serves as a benchmark for modernising agricultural education in Europe and beyond.

Results

Analysis of contemporary scientific publications and reports by international organisations has revealed that the system of engineering education within the European Union has undergone significant transformations over the past decade. The main trends include the reorientation of educational programmes towards practical skills, the development of digital competence, and the strengthening of integration with business. In the works of Czech researchers (*Klus, 2021*), it is emphasised that the effectiveness of engineering training in the agro-industrial sector depends on the ability of educational programmes to respond promptly to technological challenges in production. Studies conducted by the OECD (*Education at a Glance…, 2020*) and the European Commission highlight the necessity of applying dual models that enable students to combine academic learning with work experience at enterprises.

The Czech Republic serves as an illustrative example in this context. Its educational system has preserved the traditions of the classical technical school while complementing them with innovative approaches, such as the establishment of simulation centres, digital laboratories, and the active involvement of enterprises in the educational process. Scholars note that these elements not only enhance the quality of graduates' training but also contribute to their competitiveness in the labour market. Thus, the analytical review confirms the high relevance of the Czech experience for Ukraine, where the gap between education and production needs remains a critical issue.

A comparison of educational programmes in Czech and Ukrainian universities in agro-engineering and agricultural machinery reveals profound differences not only in the structure of the educational process but also in the approaches to forming the competencies of future

engineers. An analysis of the curricula of the Czech University of Life Sciences in Prague and Mendel University in Brno shows that these institutions devote considerable attention to the practice-oriented component of education. On average, from 40% to 50% of study time is allocated to laboratory work, industrial placements, and work in educational and research farms. This ensures not only the assimilation of theoretical knowledge but also developing practical skills in working with modern machinery and technologies. Ukrainian higher education institutions, such as NUBiP of Ukraine and VNAU, also include production practice modules in their programmes; however, the proportion of such training usually does not exceed 25–30%. Students mostly undertake internships during the summer period, and these placements are not always integrated into the educational process as a logical continuation of the theoretical course, which reduces the effectiveness of learning.

Significant differences are also observed in the integration of digital technologies into education. In the Czech Republic, the digitalisation of the educational process has acquired a systemic character: curricula include courses in CAD/CAM systems, 3D modelling and printing, robotics, automated production control systems, the use of sensors, and precision farming technologies. Students gain experience working with digital simulators that replicate real production scenarios in a virtual environment without risk to equipment or output. Furthermore, elements of augmented and virtual reality are actively applied in training to operate the latest machinery. In Ukraine, digital disciplines are still mostly represented by separate courses ("Information Technologies", "Computer Modelling of Processes") that are not integrated throughout all levels of education. This means that students acquire knowledge of digital tools in a fragmented way, whereas in the Czech Republic, digitalisation is embedded in almost every module and is linked to specific engineering tasks.

Another fundamental factor is the implementation of dual education. In the Czech Republic, it has a widespread and systemic character: students combine their studies with work placements at partner enterprises such as Zetor Tractors, Agrostroj or Farmet. This enables them not only to gain experience but also to adapt to real production conditions during their studies. In Ukraine, dual education remains at the developmental stage and exists mainly in the form of isolated pilot projects. Some universities are beginning to conclude agreements with enterprises to involve students in internships. However, these processes still lack clear systemic support from the state, and their scale is insufficient to significantly improve the labour market situation.

An important aspect of comparison is also the level of international integration. Czech universities are actively involved in programmes such as (*Annual Report…, 2021*) Erasmus+, CEEPUS, and Horizon Europe, which allow students to participate in international academic exchanges, internships, and joint research projects. This not only enhances the mobility of students and teachers but also fosters their ability to work in a multicultural environment, promotes foreign language proficiency, and supports integration into the European educational space. Ukrainian universities also take part in these programmes, though on a much smaller scale due to limited funding, a lack of international agreements, and an insufficient number of partnership projects. As a result, Ukrainian students have fewer opportunities to engage in research at the European level, creating additional barriers to their competitiveness in the labour market.

The analysis demonstrates that Czech agro-engineering programmes possess a more balanced structure that combines fundamental knowledge, applied engineering disciplines, digital technologies (*Progressing…, 2022*), and practice-oriented training. In Ukraine, by contrast, the focus remains largely on the fundamental and theoretical component, which is essential for establishing a scientific foundation but often fails to provide graduates with an adequate level of practical competence. Consequently, young engineers are forced to undergo additional training directly at production sites, which increases both the time and financial costs for enterprises. In the Czech Republic, graduates integrate rapidly into production teams because, during their studies, they already adapt to real-life working conditions and familiarise themselves with industrial processes.

Thus, an in-depth analysis has demonstrated that the Czech model of training engineers in agricultural mechanical engineering is more flexible, modern, and responsive to contemporary challenges. It is oriented towards the integration of science, education, and practice, ensures effective interaction between universities and industry, and opens broad international opportunities for students. The Ukrainian education system requires the strengthening of its practical component, systematic implementation of the dual model, integration of digital technologies at all levels of the educational process, and expansion of international cooperation. These directions may serve as the foundation for modernising programmes and enhancing the competitiveness of Ukrainian graduates under current conditions.

One of the key innovative directions in the development of engineering education in the Czech Republic is the systematic use of digital laboratories and simulation complexes. These make it possible to reproduce models of technological processes in agricultural production under conditions as close to real ones as possible, yet without the risk of material losses or equipment damage. This is particularly important in agro-engineering, where practical training involves high-cost machinery and complex production systems. In modern laboratories, students have the opportunity to work with interactive stands combining traditional mechanical equipment and digital monitoring systems, as well as software for 3D modelling and simulation of production processes. Such tools foster the development of analytical thinking, the ability to make technical and technological decisions, and to predict the consequences of various actions already at the modelling stage. In comparison with Ukrainian institutions, where such practices are only gradually being introduced, Czech universities already possess a well-established system for the use of simulators in the educational process, which positively influences the quality of graduate training.

An equally important component is the implementation of dual education. In the Czech Republic, it is based on close cooperation between universities and industrial enterprises, allowing students to receive academic training and practical work experience simultaneously. This ensures the formation of comprehensive professional competencies that encompass both fundamental knowledge and applied skills required in production. According to data from the Czech University of Life Sciences, more than half of the students enrolled in dual programmes receive job offers even before graduation. Moreover, enterprises gain the opportunity to train personnel adapted to their specific technological needs, creating an effective mechanism for interaction between education and production. In Ukraine, however, dual education remains in the formative stage: there are pilot projects in individual universities (*Education at a Glance…,*

2020), yet they have not been widely extended to engineering students, which limits their influence on the labour market.

International academic mobility is also a powerful tool for enhancing the effectiveness of engineering training. In the Czech Republic, students actively participate in programmes such as (*Annual Report…, 2021*) Erasmus+, CEEPUS, and Horizon Europe. This allows them not only to expand their scientific horizons but also to acquire practical experience in foreign universities and companies. Statistical data indicate that 30–35% of students of agro-engineering specialisations take part in international internships during their studies, which significantly increases their competitiveness in the global labour market. For Ukraine, these opportunities are also available; however, their utilisation is limited by financial constraints and a lack of systematic state support. This creates unequal conditions for students and reduces the integrative potential of Ukrainian engineering education.

Another example of innovative practice is the cooperation between universities and industrial partners, which in the Czech Republic has a systemic character. Large mechanical engineering companies such as Zetor Tractors, Agrostroj Pelhřimov, and Farmet are directly involved in the educational process, providing equipment, organising internships, and engaging students in research and design projects. As a result, universities gain access to modern machinery and production practices, while students acquire real experience of working in production teams. In Ukraine, similar cooperation also exists but mostly in the form of local initiatives or individual partnership agreements that lack a systemic nature. This reduces the effectiveness of such practices at the mass level of engineering education.

All these innovative approaches have a significant impact on the competitiveness of graduates. The practical result of their implementation is reflected in the high level of employment: more than 80–85% of Czech graduates in engineering specialisations find employment within the first six months after graduation, which significantly exceeds the corresponding indicators in Ukraine. Furthermore, the average salary level of agro-engineers in the Czech Republic is several times higher than in Ukraine, indicating a greater economic attractiveness of the profession. Thus, the role of key innovative practices in the Czech Republic is decisive for shaping a high-quality educational environment capable of meeting modern challenges and ensuring a high level of competitiveness for young professionals in both domestic and international labour markets.

Statistical analysis of workforce training and labour market conditions in the field of agro-engineering reveals striking differences between the Czech Republic and Ukraine, caused by both economic structure and educational policy. In the Czech Republic, although the agricultural sector is smaller in scale compared to mechanical engineering or the automotive industry, it remains a strategic area of the economy that consistently generates demand for engineers in mechanisation, energy, biotechnology, and digital production management systems. According to data from the Ministry of Agriculture of the Czech Republic, over the past five years the demand for agro-engineering specialists has ranged between 5,000 and 7,000 vacancies annually. This is also confirmed by labour market statistics: according to (*Agricultural Engineer Salary…, 2023*) SalaryExpert and the Czech Statistical Office (ČSÚ), more than 4,800 vacancies for agricultural engineers were registered in the country in 2023 alone.

In the Czech Republic, there is a clearly traceable correlation between the quality of

educational training and the speed of graduates' employment. According to data from the Czech University of Life Sciences in Prague, over 85% of graduates of the *Agricultural Engineering* programme find employment within the first six months after obtaining their degree. A similar trend is observed at Mendel University in Brno: graduates of agro-engineering programmes secure jobs not only in the Czech Republic but also in neighbouring EU countries, owing to degree recognition and mobility within the common European educational area. A considerable proportion of students receive job offers while still studying, facilitated by dual education programmes and industrial placements at enterprises such as Zetor Tractors, Agrostroj Pelhřimov, Farmet, Bednar FMT, and other manufacturers of agricultural machinery.

Wages are also an important indicator. The average annual salary of an agricultural engineer (*Agricultural Engineer Salary…, 2023*) in the Czech Republic is approximately CZK 879,000 (around EUR 35,000), which is four to five times higher than the average in Ukraine. Young professionals with minimal experience earn about CZK 600,000 per year, while specialists with extensive experience and high qualifications may earn over CZK 1.2 million. For comparison, the average salary in agricultural machinery manufacturing in Ukraine in 2024 was about UAH 18,000–22,000 per month (approximately EUR 6,000–7,000 per year), indicating a significant gap in the capacity to motivate and retain qualified personnel.

The dynamics of change is also worth considering. Between 2015 and 2023, the earnings of agricultural engineers in the Czech Republic increased by an average of 28%, linked to the country's overall economic growth and rising productivity in the agro-industrial complex. In Ukraine, however, wage growth in this sector has been slower and has not offset high inflationary pressures, which makes the profession of agricultural engineer less attractive to young people. This is confirmed by university admission statistics: over the past five years, the number of applications for engineering specialisations in the agricultural field in Ukraine has declined by almost 20%, whereas in the Czech Republic relative stability or even a slight increase in demand for these programmes has been recorded, driven by competitive conditions for education and employment.

Particular attention should be paid to the quantitative composition of students. For instance, Mendel University in Brno has a total enrolment of about 9,665 students, of whom nearly 1,200 study in agricultural engineering programmes. At the Czech University of Life Sciences in Prague, the number of students exceeds 17,000, with more than 2,000 enrolled in the Faculty of Engineering. By contrast, in Ukraine, several times fewer students are admitted annually to agricultural engineering programmes, and this number continues to decline. The main reasons are demographic decline, labour migration, and the lower attractiveness of the profession due to lagging wage levels.

Another significant parameter is graduate mobility. In the Czech Republic, more than one-third of young agricultural engineers have international internship or exchange experience upon graduation, which enhances their competitiveness. Ukrainian graduates also participate in Erasmus+ (*Annual Report…, 2021*) and bilateral university exchange programmes, but their proportion remains much lower—no more than 8–10%. This disparity limits employment opportunities at the international level and reduces the potential for integrating Ukrainian specialists into the global labour market.

A comparison of these data makes it possible to assert that the Czech Republic has

developed an effective model of interaction between educational programmes, the labour market, and state mechanisms for supporting young professionals. The educational system is aligned with the needs of the economy; the labour market guarantees a decent wage level and stable demand; and dual education (*Education at a Glance…, 2020*) together with international integration ensures the rapid adaptation of graduates. In Ukraine, however, the situation is complicated by the lack of systematic cooperation between universities and industry, lower remuneration levels, and limited opportunities for international mobility. All these factors highlight the urgent need to modernise educational programmes, create favourable conditions for employing young professionals, and enhance the prestige of the agricultural engineering profession.

The analysis of the Czech experience in training engineering personnel for the agro-industrial machinery sector makes it possible to identify a number of practices with high potential for adaptation in Ukraine. First and foremost, this concerns the dual education system, which in the Czech Republic constitutes an integral element of cooperation between universities and enterprises. Its implementation in Ukraine could significantly enhance the level of students' practical training, ensure their adaptation to real production conditions during the period of study, and shorten the phase of professional adjustment after employment. To achieve this, it is necessary to strengthen legislative support for dual programmes, create incentives for enterprises to participate in student training (such as tax benefits and targeted state programmes), and establish a clear mechanism for distributing responsibilities between universities and business.

The 2nd key area is the development of modern digital infrastructure within universities. In the Czech Republic, digital laboratories, simulation complexes, and interactive learning environments have become an integral part of the educational process, enabling students not only to master technical skills but also to develop systems thinking, analytical capacity, and the ability to make technical and technological decisions in simulated production contexts. For Ukrainian higher education institutions, the establishment of similar laboratories is extremely relevant, as they may serve as a bridge between classical engineering education and the contemporary challenges of the digital economy. The implementation of such projects is feasible through EU grant support, participation in international programmes such as Horizon Europe, (*Annual Report…, 2021*) Erasmus+, and COST, as well as through the attraction of private investment and partnerships with equipment manufacturers.

The 3rd important direction involves expanding the participation of Ukrainian universities in international academic mobility programmes. The Czech experience demonstrates that participation in (*Annual Report…, 2021*) Erasmus+, CEEPUS, and bilateral projects contributes not only to improving the quality of student training but also to integrating educational institutions into the European educational and scientific space. For Ukraine, the priority should not only be to increase the number of academic exchange agreements but also to ensure their accessibility to a broader range of students and academics, particularly those from regional universities. To this end, effective funding mechanisms must be established to allow students to take part in international programmes regardless of their socio-economic background.

The 4th aspect is the systematic cooperation between universities and industry. In the Czech Republic, leading companies in the agricultural machinery sector actively engage in the

educational process, providing equipment, funding laboratories, organising internships, and supporting research projects. This creates an environment in which students can directly work with cutting-edge technologies and gain experience within real production teams. In Ukraine, it is necessary to more actively involve machinery enterprises in collaboration with universities, create joint innovation centres, technology parks, and engineering clusters. This would not only improve the quality of education but also contribute to the development of national mechanical engineering.

Furthermore, the transfer of Czech experience should include the development of systems for evaluating the effectiveness of educational programmes and graduates. In the Czech Republic, indicators such as employment rates, graduate salary levels, and employer survey results are widely used, enabling timely adjustments to curricula and programme content. In Ukraine, a similar monitoring system is worth implementing to ensure a flexible response to labour market changes and adapt the educational content to the real needs of the agro-industrial complex.

From a broader perspective, it would be advisable to establish a state programme for supporting innovation in agro-engineering education, modelled on Czech and European practices. Such a programme could include funding for the creation of digital laboratories, support for dual education schemes, stimulation of university-industry partnerships, expansion of international integration, and the development of quality assessment mechanisms. Its implementation would enhance the prestige of the agricultural engineering profession, reduce the outflow of young specialists abroad, and increase Ukraine's competitiveness in the agro-industrial machinery sector.

Thus, the Czech experience cannot be mechanically transferred to Ukraine; however, it offers a range of effective solutions which, when appropriately adapted, can ensure a qualitative renewal of the engineering education system. This requires political will, institutional support, and the consolidation of efforts by the state, universities, and businesses. Successful implementation of these recommendations would contribute to the creation of a modern, competitive system for training engineers in Ukraine's agro-industrial complex that meets European standards and the strategic objectives of national economic development.

Discussion

The study revealed that the system of engineering personnel training in the Czech Republic demonstrates a high level of efficiency due to the comprehensive integration of educational, scientific, and industrial practices. However, the mere presence of positive results does not necessarily imply the universality of this model—it has both strengths and weaknesses that determine its potential opportunities and risks when adapted to the Ukrainian context.

Among the strongest aspects are the systematic nature and stability of the educational process. The Czech model shows that educational policy operates in close alignment with economic needs: businesses are interested in training engineers, while universities respond to these demands through the structure of their curricula. As a result, a continuous cycle of personnel training is established, in which students not only obtain a diploma but also acquire practical professional competences during the learning process. An additional advantage is the high level of internationalisation of education—participation in numerous European mobility

programmes enables Czech students to integrate into the global labour market, contributing to both their professional development and the growing prestige of engineering specialisations.

Nevertheless, the success of the Czech system is partly determined by external factors that are difficult to reproduce in Ukraine. A significant proportion of infrastructural projects and educational innovations is financed through European funds, creating a dependence on external resources. This may become problematic in the event of reduced funding or shifts in EU priorities. Another weakness lies in the somewhat limited attention to fundamental scientific research. The focus on rapid practical results sometimes diminishes opportunities for developing basic science, which in the long term may constrain innovation potential. Furthermore, the active participation of students in international programmes generates the risk of a "brain drain", as a portion of graduates remain employed abroad—a challenge even for the Czech Republic itself.

For Ukraine, these aspects are important primarily as lessons. The strengths of the Czech model are worth using as benchmarks: practice-oriented education, digitalisation, partnership with business, and integration into international programmes may serve as the foundation for modernising the national education system. At the same time, the weaknesses indicate which risks are worth avoiding—dependence on external funding, excessive focus solely on practical outcomes, neglect of fundamental science, and the loss of young professionals through migration.

Thus, the discussion confirms that the Czech experience is valuable and may serve as a reference point for Ukraine. However, its implementation must be selective and adapted to the national context. The optimal path could involve combining the best Czech practices with the preservation of Ukrainian scientific traditions and the formation of domestic institutional mechanisms to support engineering education.

Conclusion

The study demonstrates that examining the experience of the Czech Republic in the field of agro-engineering education is of exceptional value for Ukraine, not only as an example of innovation implementation but also as a model of strategic interaction between education, science, and industry. The Czech system confirms that an emphasis on students' practical training, close cooperation with industry, and the use of digital technologies can significantly enhance the efficiency of specialist preparation.

The synthesis of the conducted analysis allows several important conclusions to be drawn. Firstly, the success of educational reforms depends on systemic coherence: only the integration of academic training with industrial practice and research activity creates the conditions necessary for training a new generation of engineers. Secondly, international integration of educational programmes is not an additional option but a key factor determining graduates' competitiveness. Thirdly, enhancing the prestige of the engineering profession requires not only educational transformations but also a comprehensive state policy aimed at supporting young researchers and developing national mechanical engineering.

At the same time, the Czech experience also reveals potential risks. Excessive dependence on external funding, the decline of fundamental science in favour of applied objectives, and the outflow of young specialists abroad are challenges that Ukraine must consider to avoid similar

problems. This implies that mechanical copying of a foreign model is inappropriate—adaptation is required, taking into consideration national characteristics, available resources, and long-term goals.

Further research in this direction should focus on several aspects:

- the development of concrete mechanisms for integrating dual education in Ukraine;
- the search for funding models for universities' digital infrastructure;
- the study of other European countries' experience to design a combined model for the modernisation of agro-engineering education.

Thus, the Czech experience is not a ready-made recipe but rather a valuable resource for re-thinking Ukraine's prospects. Its strengths can serve as a catalyst for reforms in Ukraine, while its weaknesses act as a warning against risks that are worth avoiding. It is precisely selective and adapted integration of this experience that can ensure the sustainable renewal of engineering education in Ukraine and its correspondence to the challenges of contemporary agro-industrial production.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Agricultural engineer salary in Czech Republic. (2023). *SalaryExpert*. https://www.salaryexpert.com

Annual Report 2021. (2021). *Erasmus+. European Commission*. https://erasmus-plus.ec.europa.eu

Annual Report 2022. (2022). *Mendel University in Brno*. https://mendelu.cz

Česká zemědělská univerzita v Praze. (2023). *Annual report 2023*. (In Cze.). https://www.czu.cz

Digital agriculture: Supporting farmers in transition. (2020). *FAO*. https://www.fao.org

Education at a glance 2020: OECD indicators. (2020). *OECD*. Paris: OECD Publishing. https://doi.org/10.1787/69096873-en

Education policy strategy 2030+. (2022). *Ministry of Education, Youth and Sports of the Czech Republic*. Prague. https://www.msmt.cz

Engineering for sustainable development: Delivering on the Sustainable Development Goals. (2021). Paris: UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000375648

Klus, M. (2021). Innovations in higher technical education in Central Europe. *Journal of Engineering Education Research*, *15*(2), 45–57.

Progressing toward the European Education Area. (2022). *European Commission. Publications Office of the EU*. https://op.europa.eu/en/publication-detail/-/publication/1da6d9cd-6703-11ed-b14f-01aa75ed71a1/language-en

Research for AGRI Committee – The future of EU agricultural policy. (2021). *European Parliament*. https://www.europarl.europa.eu/RegData/etudes/STUD/2022/699620/IPOL_STU(2022)699620_EN.pdf

Schwab, K. (2017). *The fourth industrial revolution*. Geneva: World Economic Forum.

Skills for agriculture in transition economies. (2021). *European Training Foundation*. https://www.etf.europa.eu

Transforming agricultural education and training in Eastern Europe. (2020). *World Bank*. https://openknowledge.worldbank.org

Žalman, M., & Dvořák, P. (2019). Dual education in the Czech Republic: Challenges and perspectives. *International Journal of Vocational Education*, *8*(3), 112–126.

Serhiy A. Shargorodskiy [a][19]

Comparative Analysis of the Implementation of Information Technologies in Higher Education Institutions of the Czech Republic and Ukraine [15]

Abstract: This article examines the theoretical and practical aspects of informatization of education as a key factor in improving the effectiveness of the educational process in higher education. The scientific novelty of the study lies in the comprehensive comparative analysis of the implementation of information technologies in higher education institutions of the Czech Republic and Ukraine. The article reveals new aspects of digital transformation in education by comparing institutional, infrastructural, and pedagogical approaches in two European countries with different socio-economic contexts. The originality also consists in identifying three interrelated levels of informatization — physical, logical, and applied — and establishing their influence on the quality of the educational process and digital competence formation. The object of the study is the process of informatizing higher education. The subject of the study is the methods, mechanisms, and results of implementing information technologies in universities of the Czech Republic and Ukraine. The purpose of the study is to determine the role and effectiveness of information technologies in enhancing the quality of higher education, as well as to identify similarities and differences in their implementation within Czech and Ukrainian educational systems. The author concludes that informatization is a strategic direction for educational development, ensuring the formation of a digital culture, enhancing the competence of teachers and students, and integrating them into the global information space.

Keywords: informatization of education, information technology, digitalization, information culture, IT competence, Ukraine, Czech Republic.

Introduction

The current stage of societal development is characterized by the rapid computerization of all spheres of human activity, and especially education. Improving the quality of specialist training in higher education largely depends on the integration of computer science advances and new information technologies into the educational process. Researchers note that computer science as a scientific field is considered at three levels: physical (hardware, software, and communications), logical (information technology), and applied (user-level systems). At the same time, computer science tools not only improve teaching methods but also shape the information culture of the younger generation, a prerequisite for entering the "information society".

Researchers' works demonstrate a trend toward a gradual development of the computerization of education: from computerization (the initial saturation with technical means), through personalizing information resources (the widespread adoption of computing technology and the development of computer literacy), to socializing information funds (the creation of integrated databases and the provision of remote access). Another important factor is the development and implementation of educational programs that take into account the specifics of using the latest IT technologies in teaching, research, and education management.

Several scientific papers compare international and domestic experiences in digitalizing

[a] Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department Head, Department of Agricultural Machinery and Equipment, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.

education. Specifically, research findings indicate that in the Czech Republic, digital literacy is integrated into national educational standards and actively supported at the state level, while in Ukraine, the process of informatization is dynamic but faces funding challenges and unequal access to infrastructure. Despite these challenges, Ukrainian higher education is gradually adapting to global trends, implementing modern educational platforms, electronic resources, and collaborating with IT companies.

Thus, an analysis of recent publications confirms that informatization is a key factor in improving the effectiveness of the educational process. This encompasses not only technical support but also the development of a digital culture, the development of information competence among teachers and students, and the integration of education into the global information space.

An analysis of recent research and publications. Improving the quality of higher education specialist training is largely determined by advances in computer science, which are being integrated into the educational process.

Computer science as a scientific field can be considered at three levels:

- Lower (physical) is software and hardware of computing and communications technology;
- Middle (logical) is information technology;
- Upper (intended for the user) is applied information systems.

Computer science tools can also be used to engage the younger generation in information culture, which is becoming increasingly relevant in connection with the transition to an "information society". According to scientists, this transition is planned for 2050 in Ukraine, 2020 in the USA and Japan, and 2030 in the leading countries of Western Europe.

The first stage of informatization has a specific purpose—the computerization of society. The most significant results of this stage in education include the extensive dissemination and initial saturation of the Ukrainian university system with computer technology. However, their current level of equipment is insufficient, averaging 3 to 5 computers per 100 students. This is an order of magnitude lower than in developed countries, and for some US universities, there is one personal computer or one workstation per student (university data). At the same time, this stage marks the formation of the foundations of information culture, as well as the beginning of the computer-based development of existing information resources in education.

The second stage of informatization can be summarized as personalizing information resources, which is associated with the intensive use of computing technology at all levels of education, the conversion of information resources to computer (machine) form, and a sharp increase in computer literacy among young people.

The third stage can be defined as socializing information resources, which will lead to the emergence of a high level of information culture, the creation of integrated computer information resources with remote access, and further development to fully meet the growing information needs of the population.

The scientific novelty of the study lies in the comprehensive comparative analysis of the implementation of information technologies in higher education institutions of the Czech Republic and Ukraine. The article reveals new aspects of digital transformation in education by comparing institutional, infrastructural, and pedagogical approaches in two European countries with different socio-economic contexts. The originality also consists in identifying

three interrelated levels of informatization—physical, logical, and applied—and establishing their influence on the quality of the educational process and digital competence formation.

The object of the study is the process of informatizing higher education.

The subject of the study is the methods, mechanisms, and results of implementing information technologies in universities of the Czech Republic and Ukraine.

The purpose of the study is to determine the role and effectiveness of information technologies in enhancing the quality of higher education, as well as to identify similarities and differences in their implementation within Czech and Ukrainian educational systems.

According to the purpose of the study, the main tasks:

- analyse theoretical and methodological foundations of educational informatization;
- study the stages of informatization and their impact on the efficiency of educational processes;
- compare the level of IT implementation in Czech and Ukrainian higher education institutions;
- identify systemic problems and formulate recommendations for improving digital transformation in Ukrainian education based on Czech experience.

Methods

The research employed a complex of general scientific and special methods to ensure the reliability and objectivity of the results.

Among general scientific methods, the study used analysis and synthesis to examine theoretical approaches to informatization and its structural levels; induction and deduction to generalise empirical data and derive conclusions; and system-structural analysis to identify interconnections between technical, pedagogical, and managerial components of digital transformation in education. The comparative method was used to contrast the Czech and Ukrainian experiences of implementing IT in education, revealing their convergent and divergent features.

Among special methods, the study applied content analysis of scientific and statistical reports, educational strategies, and institutional documents of Czech and Ukrainian universities; expert assessment of digital competence development; and classification and modelling to structure the stages of informatization—computerization, personalization, and socialization. Empirical generalisation allowed identification of common trends in e-learning, cloud technologies, and artificial intelligence integration in educational processes. The methodological basis of the research is the systemic approach, which views informatization as a dynamic, multi-level process of socio-technical interaction between educational institutions and the digital environment.

Literature Review

A review of the literature demonstrates that the informatization of education is a multidimensional process encompassing technological, pedagogical, and organisational aspects. According to Ovcharuk (*2020*), digital competence has become a key indicator of professional readiness of teachers within European educational standards. Similarly, Stoika (*2021*) and

Kostolanyová et al. (*2023*) emphasise that the Czech educational system systematically integrates digital literacy into curricula through the DigComp and DigCompEdu frameworks.

Holubová and Jansa (*2020*) traced twenty years of e-learning development at Czech universities, confirming the institutional maturity of blended learning models, while Dvorakova (*2022*) showed that digitalization has become an essential component of executive education and lifelong learning in the Czech Republic. In contrast, studies by Voronkin (*2021*) and Popel & Shyshkina (*2018*) highlight that Ukraine is in a transitional phase, with uneven access to IT resources and reliance on cloud and open-access educational platforms such as Moodle and Google Classroom.

Research by Hlásná, Klímová, and Poulová (*2017*) revealed that Czech primary education ensures early development of digital literacy, supported by infrastructure and teacher training. Similar approaches are described in international analyses of ICT integration, showing that the Czech Republic belongs to the group of EU leaders in educational digitalization. Conversely, Ukrainian authors (*Vakaliuk et al., 2020*; *Voronkin, 2021*) underline the rapid but fragmented nature of digital transformation, often driven by donor-funded initiatives.

Thus, the existing body of research confirms the duality of informatization trends: a structured, state-supported digitalization model in the Czech Republic and a dynamically evolving, decentralised model in Ukraine. The comparative analysis presented in this article contributes to bridging this knowledge gap by identifying transferable practices and evaluating their applicability in the Ukrainian context.

Results

A subprogram for developing and implementing information technologies in education, which has been developed in the Department of Economic Cybernetics and Informatics as a step-by-step program, should occupy a special place in the educational informatization program.

It is worth noting that research and teaching staff in higher education have currently developed a significant number of informatics products that are used both in the educational process and in scientific research. Developments in organizational support for higher education management also occupy a special place among these.

With regard to the educational process and scientific research, new information technologies are of fundamental importance.

Unlike traditional educational technologies, information technology focuses on information as both the subject and the outcome.

Therefore, the quality and application of information products developed within this technology are largely determined by the computers used, operating systems, database structure, etc.

Any information technology involves two problems:

1. Solving specific functional problems of the user;

2. Organizing the information processes that support the solution of these problems. Based on their nature, all problems are divided into those formalized and those that are difficult to formalize. For formalized problems, a well-known typical solution sequence includes the formation or selection of a mathematical model, the development of an algorithm and program, and the implementation of calculations. Most subject curricula include such problems, and

therefore the use of information technology for these problems is traditional and is widely used and developed today.

Much more common are difficult-to-formalize problems, which include problems that do not have precise mathematical models during formalization and are therefore solved using knowledge representation models such as logical, algorithmic, semantic, and frame-based. These models are used to reduce difficult-to-formalize problems to elementary problems and logically infer a solution. This ultimately leads to the formation of knowledge bases within expert systems and other types of intelligent systems for educational and scientific purposes.

Organizing information processes within the framework of educational information technologies presupposes the identification of such basic processes as data transfer, processing, organization of storage and accumulation, and the formalization and automation of knowledge.

Improvements in problem-solving methods and information process organization are leading to entirely new information technologies, including the following in relation to education:

1. Computer-based educational programs, including electronic textbooks, simulators, laboratory workshops, and testing systems.
2. Educational systems based on multimedia technologies, built using personal computers, video equipment, and optical disk drives.
3. Intelligent and educational expert systems used in various visual fields.
4. Distributed databases across knowledge areas.
5. Telecommunications, including email, teleconferencing, local and regional communication networks, data exchange networks, and the like.
6. Electronic libraries, distributed and centralized publishing systems.

Specific software and hardware within these technologies are being developed in parallel at different higher education institutions and are often duplicated. However, the main drawback of the current approach to applying computer science advances in education is the lack of scientific and methodological support for the use of new information technologies. The use of computers in education should not preclude the training of specialists in a realistic, visual field. That is, replacing real physical phenomena with mere model representations on a computer screen is not permissible. Requirements for skills, knowledge, and habits in computer science should vary depending on the type of higher education institution, the nature of training, and the specialty. The objective need to improve the effectiveness of education periodically leads to sudden breakthroughs in the use of tools for organizing the work of all participants in educational activities: students, teachers, scientists, and management personnel. These tools, which claim to fundamentally transform centuries-old understandings of the work functions of all participants in the educational process, include various computer and information technology tools and technologies. Undoubtedly, these tools have already had a tremendous impact on traditional educational paradigms, generating promising hopes for the broad possibilities of dramatically improving the quality of education through increasingly automated systems that also boast high speed, operational memory, and long-term memory. The main areas of use of information and computer tools in education encompass four main areas.

Computer technology and informatics as objects of study (*Ovcharuk, 2020*). This area is not directly related to issues of improving the effectiveness of education. However, historically, the

emergence of computers in education was associated specifically with the teaching of the fundamentals of computing, first in vocational education and then in general education.

The study of computer technology and informatics, like the study of any other academic discipline or group of disciplines at various levels of education, is directly related to the issue of educational content in general. The presence of a particular subject in the preparation of students in general and vocational education is determined, first and foremost, by the objectively current and future needs of socio-economic and scientific-technical progress, as well as the personal educational needs of those studying. However, despite the importance of the didactic and methodological issues associated with finding ways to effectively study a particular discipline, it is extremely important to justify the very feasibility of including this discipline in the education system, especially general education, at the border of the natural sciences and humanities, which are overloaded with "traditional" subjects. If a new subject is included in the curriculum, it should clearly define its contribution to the overall objectives of this educational subsystem, which can be enriched and developed through its use. The need to study computer technology and information technology, along with arguments and justifications, is no longer necessary today.

Computers as a means of increasing the effectiveness of teaching (*Popel & Shyshkina, 2018*). It is in this capacity that computers and information technology are viewed as components of the educational system that are not only capable of fundamentally transforming the very understanding of the category "tool" in relation to the educational process, but also significantly impact (presumably, only positively) the entire delivery of components of a given local educational system: the entire content, methods, and organizational forms of instruction, as well as the upbringing and development of students in educational institutions of any profile. These expectations and prospects are then extended to the entire education system, the entire extensive network of educational services, and the entire field of education in its most general sense—as an integral component of any society, fulfilling its most important functions. The computer, therefore, is becoming an exceptionally promising tool, capable of truly ensuring the necessary shifts in the progressive development of humanity, increasing its integrated intellectual power, and intensifying its scientific, technological, and economic activities.

Computers as a means of increasing the effectiveness of research activities in education (*Stoika, 2021*). Modern scientific research, especially interdisciplinary and complex research, can no longer be successful without comprehensive information support. Such support involves searching for sources of the "most current" scientific and educational information, selecting and selectively evaluating this information, storing it, which ensures an appropriate level of classification and free access to it by potential consumers, and, ultimately, the prompt provision of the necessary information to the user upon request. Each stage of the above-mentioned process of information support for scientific research varies significantly and increases in labor intensity. As interdisciplinary information accumulates, it becomes virtually inaccessible to the individual researcher. This conclusion applies to all fields of science, but the field of education, as demonstrated above, is distinguished by its increased multifactorial nature. Almost any research in this area is systemic and comprehensive in nature, regardless of whether it concerns the substantiation of local components of educational systems (goals, content, methods, means, organizational forms), or the development of a long-term policy and strategy for the

development of education in general. The information capabilities of computers integrated into extensive information, computer, and telecommunications networks are truly enormous. Therefore, the importance of this direct informatization in education is entirely obvious. The challenge is to ensure that the system of research problems solved using such powerful tools is commensurate with their significance, a syndrome that still exists in science—the embezzlement of resources and energy.

Scientific research in higher education is worth focusing primarily on understanding the functioning of educational sciences, which can reasonably be called educational science, a unique science of sciences.

Computer and informatics as a component of the educational and pedagogical management system (*Vakaliuk et al., 2020*). This area of informatization is linked to the process of managerial decision-making at all levels of educational activity—from the day-to-day management of an educational institution to the management of an entire region at the federal and regional levels. It is quite obvious that to make optimal management decisions, a wide variety of information is required, both of a background nature about the development trends of the external socio-economic and socio-cultural environment, and of an educational nature itself.

The aforementioned areas are related to each of the four spheres, which directly influence the development of one or the other and, at the same time, are influenced by the corresponding area of computer use in education. These areas include:

1) the socio-economic sphere of society;
2) the philosophical and methodological sphere (referring to the sphere of interdisciplinary scientific knowledge);
3) the scientific and technical sphere;
4) the psychological and pedagogical sphere.

The scientific substantiation of a comprehensive, integrated concept of informatization in education must be based on a substantive interpretation of both the aforementioned four areas and the four spheres of mutual influence, as well as all the connections between them. This task is highly complex and requires an interdisciplinary, systems approach, integrative logic, and conceptual design methodology. Given its complexity and relative novelty, this problem has not yet been solved, but it urgently demands a solution in the near future. The socioeconomic sphere of society essentially predetermines the need for mass computer-based learning and the widespread use of computer technology as a means of increasing the effectiveness of multifaceted educational and pedagogical activities. It is worth assuming that the very emergence of computers is an objective reality, conditioned by the development of society's material and technical infrastructure. Highest demands are constantly placed on the accuracy, speed, and reliability of the various technical systems that are constantly being developed.

Thus, it is precisely the socioeconomic sphere, interested in the proper return on education, that has dictated and continues to dictate the need for the study and use of information technology at all levels of education, including primary education. Among the diverse factors and relationships accompanying the introduction of computer technology into education, the "human-computer" relationship is undoubtedly central. The obvious globality and multifaceted nature of this problem compel us to explore all the multifaceted human-computer relationships within a specific ideological, philosophical paradigm, and philosophical-methodological

framework. Such a framework, if it is necessary, will finally materialize. It should provide general guidelines for assessing the problems of computerization. However, there is no need to overemphasize the capabilities of computers. Despite all its artificial intelligence potential, transformations, and achievements, any computer today is simply a means of enhancing the efficiency of human intellectual activity. Moreover, it is, first and foremost, an informational tool, focused (in all the nuances and specificities of highly specialized computers) on serving human needs. How to make this service (in the broad sense) most productive specifically in education is the central question of the entire multifaceted problem of informatization in education.

The fourth area of interaction and mutual influence relative to all areas of computerization is the psychological and pedagogical sphere. It is this sphere that is closest to educational practice, called upon, capable, and obligated to add practice-oriented technological effectiveness and completeness to all conceptually important socio-economic, philosophical-methodological, and scientific-technical aspects of a holistic ideology of informatization in education, all of which are more or less remote from direct educational activity.

Underestimating this particular sphere, this conceptual direction, can have a negative consequence, not only negating the desire for computer-based information support for educational systems but also directly harming all participants in the educational process, primarily students. Numerous and entirely convincing examples can be cited that confirm the effectiveness of using computers at all stages of the educational process:

- at the stage of presenting educational information;
- during the acquisition of educational material through interactive computer interaction;
- during the review and reinforcement of acquired knowledge (habits, skills);
- during midterm and final assessments and self-monitoring of achieved learning outcomes;
- during the correction of both the learning process itself and its results by improving the dosage of educational material, its classification, systematization, etc.

All these didactic and methodological possibilities are truly irrefutable. Furthermore, it is necessary to consider that the use of rationally designed computer educational programs is essential for considering not only the specifics of the substantive (scientific) information, but also the psychological and pedagogical patterns of assimilation of this information by a specific contingent of students. This allows for the individualization and differentiation of the learning process, infusing it with elements of "educational games" that stimulate cognitive activity and independence in those learning. Computer-based learning is truly effective, facilitating the implementation of guiding didactic principles for organizing the educational process, infusing teachers' work with fundamentally new content, and enabling them to focus on key learning, educational, and developmental functions.

We will analyze the level of implementation of computer technologies in education.

1. Primary and Secondary Education

In the Czech Republic, digital literacy is an integral part of the curriculum—it is based on the European Digcomp framework, and is assessed through national digital competency tests. The government actively invests in school technology, including computers, stable internet, and interactive whiteboards. Popular platforms include Moodle, Bakaláři, Microsoft 365, and

Google Workspace. Students begin learning programming in middle school (Scratch, Python).

In Ukraine, digital literacy is also included in the curriculum, but its implementation often depends on the specific school. Material and technical resources are provided primarily through local budgets or parental contributions. The main educational platforms are the All-Ukrainian Online School, Google Classroom, and Zoom. Programming is typically taught as an elective or at Stem Schools. Systematic assessment of IT competencies is currently in the pilot phase (for example, the IT Fitness Test).

2. Higher Education

The Czech Republic offers over 20 IT programs with a strong applied foundation, extensive practical training, and internship opportunities at Avast, IBM, and Seznam.cz. Education is free for foreigners and is taught in Czech (English-language programs require a fee). Universities use their own LMS integrated with international systems, and students have access to VR/AR, AI, and cloud services.

In Ukraine, the range of IT specialties is also broad, but training is more focused on theoretical preparation. Foreigners mostly study on a fee-paying basis, in Ukrainian or English. Universities collaborate with IT companies such as Softserve, EPAM, and Genesis. Moodle, Google Classroom, and local platforms are used for training. Access to modern technologies is uneven and depends on the resources of each institution.

3. Teacher Training

In the Czech Republic, digital literacy courses are mandatory, and teachers are certified according to the Digcompedu standard. The state funds professional development and provides access to resources through Edu.cz, Dumy.cz, and methodological portals.

In Ukraine, teacher training in digital competence is primarily voluntary and is implemented through online platforms such as Edera, Prometheus, Edcamp, and the All-Ukrainian Online School. State support is partial, and most initiatives are grant- or donor-funded.

4. Government Initiatives

The Czech Republic is implementing a large-scale national program, "Digital Czech Republic 2030", aimed at developing digital infrastructure, equal access to technology, and supporting edtech startups. The state is actively promoting the implementation of AI in education.

Ukraine is integrating the digitalization of education into the strategy of the Ministry of Education and Science. Edtech support is provided through grants and international partnerships. However, the level of technical support in schools varies significantly between regions, especially in rural areas.

Discussion

The discussion of results indicates that informatization in higher education operates as both a technological and cultural transformation. The comparison between the Czech Republic and Ukraine shows that the success of digital transformation depends on systemic governmental support, sustainable infrastructure, and continuous professional development of teachers. In the Czech Republic, the implementation of the national programme Digital Czech Republic 2030 ensures strategic coordination, investment in digital infrastructure, and integration of artificial intelligence in education. Ukrainian initiatives, while progressive, remain fragmented

due to limited funding and unequal regional access.

The study highlights that informatization should be viewed not only as technical modernization but as a holistic pedagogical innovation that transforms teaching methodologies, promotes interactive learning, and builds digital culture among students and educators. Moreover, the results confirm that digital tools—such as electronic libraries, LMS platforms, and multimedia environments—enhance accessibility and inclusiveness of education. However, the lack of unified methodological support and standardisation in Ukraine hinders large-scale adoption.

Thus, sustainable informatization requires a systemic approach that combines infrastructure development, teacher training, and pedagogical adaptation to new digital realities, as successfully demonstrated in the Czech model.

Conclusion

The conducted comparative analysis confirms that informatization of higher education is a key factor in improving its quality and competitiveness. The Czech Republic's experience proves that consistent government policy, integration of digital standards, and support for educators' competence ensure the formation of a digital academic ecosystem. In Ukraine, the rapid development of online education, cooperation with IT companies, and the spread of cloud platforms demonstrate strong potential for growth, provided adequate financial and methodological support.

In conclusion, informatization must be recognised as a strategic direction of educational policy, fostering digital culture, increasing IT competence, and integrating national education systems into the global information space. The author's contribution lies in the identification of specific mechanisms and best practices of Czech educational digitalization that can be adapted for Ukraine's modernisation strategy.

Conflict of Interest

The author declares that there is no conflict of interest.

References:

Dvorakova, Z. (2022). Digitalization and Executive Education: A Czech Case. In: E. Zaramenskikh, & A. Fedorova, (Eds.), *Digitalization of Society, Economics and Management. Lecture Notes in Information Systems and Organisation*, vol 53. Springer, Cham. https://doi.org/10.1007/978-3-030-94252-6_25

Flipped classroom in the Czech Republic: Implementing a flipped classroom project in environmental education. (2024). *Proceedings of the 23rd European Conference on e-Learning (ECEL)*, 129-137. https://papers.academic-conferences.org/index.php/ecel/article/view/2732

Hlásná, H., Klímová, B., & Poulová, P. (2017). Use of information and communication technologies in primary education in the Czech Republic. *International Electronic Journal of Elementary Education*, *9*(3), 681–692.

Holubová, I., & Jansa, P. (2020). 20 years of eLearning and blended learning at Czech universities. *Proceedings of the 18th International Conference on Emerging eLearning Technologies and Applications*, 868–875. Springer. https://doi.org/10.1007/978-3-030-52575-0_77

Kostolanyová, K., Cirus, L., Javorcík, T., & Šimonová, I. (2023). A new concept of the informatics curriculum in the Czech Republic: Teacher reflection on the first year of the transition period.

Sustainability, *15*(5), 4091. https://doi.org/10.3390/su15054091
Kozlova, D., Novák, P., & Hanušová, M. (2021). The use of ICT in higher education from the perspective of students' perception: Case of the Czech Republic. *Procedia Computer Science*, *192*, 4374–4382. https://doi.org/10.1016/j.procs.2021.08.221
Kubiatko, M. (2010). Czech university students' attitudes towards ICT used in science education. *Journal of Technology and Information Education*, *2*(3), 20–29. https://doi.org/10.5507/jtie.2010.045
Ovcharuk, O. (2020). Digital competence of teacher: International tendencies and frameworks. *New Pedagogical Thought*, *4*(104), 15–21. https://lib.iitta.gov.ua/id/eprint/719492
Popel, M. V., & Shyshkina, M. P. (2018). The cloud technologies and augmented reality: The prospects of use. *CEUR-WS*, *2257*, 23. arXiv:1807.01966. https://arxiv.org/abs/1807.01966
Stoika, O. (2021). Teacher's digital competence in the European educational discourse. Educational Review. *Kyiv University of Borys Grinchenko*, *1*, 45–53. https://edreview.kubg.edu.ua/index.php/edreview/article/view/156
Šimonová, I., & Poulová, P. (2014). E-learning reflected in research studies in the Czech Republic: Comparative analyses. *Procedia – Social and Behavioral Sciences*, *116*, 1298–1304. https://doi.org/10.1016/j.sbspro.2014.01.386
Vakaliuk, T. A., Antoniuk, D. S., Morozov, A. V., & Soloviev, V. N. (2020). Green IT as a tool for design cloud-oriented sustainable learning environment of a higher education institution. *E3S Web of Conferences*, *166*, 10013. https://doi.org/10.1051/e3sconf/202016610013
Voronkin, O. (2021). The perspectives of information and communication technology of education of students in higher educational institutions of Ukraine. *Information Technologies in Education*, *49*, 149–157. https://ite.kspu.edu/index.php/ite/article/view/149

Authors:

[1] *Vitaliia S. Harkusha*, Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Architecture, Pryazovskyi State Technical University. Mariupol (Dnipro), Ukraine.
https://orcid.org/0000-0002-5016-0737

[2] *Serhii Simonov*, Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Architecture, Pryazovskyi State Technical University. Mariupol (Dnipro), Ukraine.
https://orcid.org/0000-0002-3921-0131

[3] *Andrii V. Korzh*, Candidate of Medical Sciences (Ph.D.), Senior Lecturer, Department of Anesthesiology and Resuscitation, Faculty of Retraining and Advanced Training, Ukrainian Military Medical Academy. Kyiv, Ukraine.
https://orcid.org/0009-0003-9208-2954

[4] *Olena I. Stepanenko*, Candidate of Pedagogical Sciences (Ph.D.), Associate Professor, Educational and Scientific Institute of Philology, Taras Shevchenko National University. Kyiv, Ukraine.
https://orcid.org/0000-0003-0598-6473

[5] *Olha V. Maltseva*, Doctor of Science in Philosophy, Associate Professor, Department of Sociology and Social Work, Pryazovskyi State Technical University. Dnipro, Ukraine.
https://orcid.org/0000-0002-1497-4098

[6] *Iryna O. Kryknitska*, Candidate of Philological Sciences (Ph.D.), Associate Professor, Department of Theory, Practice and Translation of English, Faculty of Linguistics, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.
https://orcid.org/0000-0003-3143-8956

[7] *Khrystyna I. Serednytska*, Candidate of Physical and Mathematical Sciences (Ph.D.), Head of the Laboratory, Pidstryhach Institute for Applied Problems of Mechanics and Mathematics, National Academy of Sciences of Ukraine. Lviv, Ukraine.
https://orcid.org/0000-0003-2037-1223

[8] *Liana V. Spytska*, Four-Time World Science Champion and Three-Time Olympic World Champion in Science, Doctor of Psychology, Ph.D. in Law, Full Professor, Department of Psychology and Pedagogy, Kyiv International University. Kyiv, Ukraine.
https://orcid.org/0000-0002-9004-727X

[9] *Taras Bondar*, Candidate of Sciences in Physical Education and Sports (Ph.D.), Senior Lecturer, Department of Theory and Methodology of Physical Education, Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy. Kremenets, Ukraine.
https://orcid.org/0000-0002-1389-6614

[10] *Viktor Holub*, Candidate of Sciences in Physical Education and Sports (Ph.D.), Associate Professor, Head of the Department, Department of Theory and Methodology of Physical Education, Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy. Kremenets, Ukraine.
https://orcid.org/0000-0003-3123-7169

[11] *Diana Melnyk*, Director, Municipal Institution "Inclusive Resource Centre of Kremenets City Council". Kremenets, Ukraine.
https://orcid.org/0009-0009-1926-558X

[12] *Ivan Riabko*, Master of Science in Biomedical Physics and Informatics, Engineer – Radiophysicist, Department of Radiation Safety, Faculty of Radiophysics, Electronics and Computer Systems, Taras Shevchenko National University of Kyiv, National Children's Specialized Hospital "OHMATDYT". Kyiv, Ukraine.
https://orcid.org/0009-0000-6748-8686

[13] *Mykyta Nechaiev*, Head of the Center, Radiology Centre, Department of Radiology and Radiation Medicine, Bogomolets National Medical University, National Children's Specialized Hospital "OHMATDYT". Kyiv, Ukraine.
https://orcid.org/0000-0002-7345-5124

[14] *Olha O. Mazurenko*, Candidate of Engineering Science (Ph.D.), Senior Lecturer, Department of Information Technology, Artificial Intelligence and Cybersecurity, Faculty of Automation and Computer Systems, National University of Food Technologies. Ukraine, Kyiv.

[15] *Mykola A. Kolisnyk*, Ph.D. in Mechanical Engineering, Senior Lecturer, Department of Power Engineering, Electrical Engineering and Electrical Mechanics, Faculty of Engineering and Technology, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.
https://orcid.org/0000-0001-5502-6556

[16] *Vitalii M. Yaropud*, Doctor of Technical Sciences, Associate Professor, Department of Machines and Equipment for Agricultural Production, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.
https://orcid.org/0000-0003-0502-1356

[17] *Olena O. Trukhanska*, Candidate of Engineering Science (Ph.D.), Associate Professor, Department of Agro-Engineering and Technical Service, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.
https://orcid.org/0000-0001-8481-8878

[18] *Ihor M. Kupchuk*, Candidate of Technical Sciences (Ph.D.), Associate Professor, Department of Engineering Mechanics and Technological Processes in Agriculture, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.
https://orcid.org/0000-0002-2973-6914

[19] *Serhiy A. Shargorodskiy*, Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department Head, Department of Agricultural Machinery and Equipment, Vinnytsia National Agrarian University. Vinnytsia, Ukraine.
https://orcid.org/0000-0003-2125-773X

Citations in APA

[1] Harkusha, V. S., & Simonov, S. (2025). Determining the impact of street art on the urban environment. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 7–17. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/cul2025-07-01

[2] Korzh, A. V. (2025). Analysis of biochemical indicators of iron metabolism in primary allogenic blood donors. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 18–27. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/med2025-07-01

[3] Stepanenko, O. I. (2025). The use of innovative technologies in ESP instruction for IT students within the framework of Open Education. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 28–42. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/ped2025-08-01

[4] Kryknitska, I. O. (2025). Shaping brand identity through metaphoric connotation: The case of Yves Saint Laurent. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 43–53. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/phl2025-07-01

[5] Maltseva, O. V. (2025). Digital educational tribes: Platform algorithms and students' academic identity. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 54–67. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/phi2025-08-01

[6] Serednytska, K. I. (2025). Study of thermal rectification in a bi-material with interfacial inhomogeneities. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 68–77. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/phy2025-07-01

[7] Spytska, L. V. (2025). Peculiarities of manifestation of paranoid delusions in the world. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 78–92. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/psy2025-08-01

[8] Bondar, T., Holub, V., & Melnyk, D. (2025). Rationale for the invariant content of physical education in the context of inclusive education. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 93–105. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/soc2025-08-01

[9] Riabko, I., & Nechaiev, M. (2025). Functional MRI training for biomedical physics and engineering students: Methodological approach to acquisition, processing and visualization. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 106–114. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/tec2025-08-01

[10] Mazurenko, O. O. (2025). Emotionally adaptive UX interfaces: A scenario-based framework for real-time personalization. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 115–124. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/tec2025-08-02

[11] Kolisnyk, M. A. (2025). Using the Czech experience of innovations in mechanical engineering and energy saving to train engineering personnel in the agricultural sector. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 125–132. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/tec2025-09-01

[12] Yaropud, V. M. (2025). Implementation of innovations in technologies and engineering: European approaches and opportunities for Ukraine (Case of the Czech Republic). Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 133–142. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/tec2025-09-02

[13] Trukhanska, O. O. (2025). Investigation of the operation of the electromechanical system of an autonomous photovoltaic pumping station. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 143–153. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/tec2025-09-03

[14] Kupchuk, I. M. (2025). Modern educational trends in agricultural engineering: The experience of the Czech Republic. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 154–165. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/tec2025-09-04

[15] Shargorodskiy, S. A. (2025). Comparative analysis of the implementation of information technologies in higher education institutions of the Czech Republic and Ukraine. Actual Issues of Modern Science. *European Scientific e-Journal*, *38*, 166–176. Ostrava: Tuculart Edition, European Institute for Innovation Development.
https://doi.org/10.47451/tec2025-09-05

European Scientific e-Journal

EU, Czech Republic, Ostrava

Publishers
European Institute for Innovation Development
Tuculart Edition

Right to conduct publication activities
IČ: 14207052

Date of Issue
September 30, 2025

EUROPEAN SCIENTIFIC e-JOURNAL
ISSN 2695-0243
DOI 10.47451/col-038-2025