UDC 378.147:51:004

https://doi.org/10.52058/2786-5274-2026-5(57)-939-955

Losyeva Nataliya Mykolaivna Doctor of Pedagogical Sciences, Professor, Head of the Department of Pedagogy, Primary Education and Educational Management, Mykola Gogol Nizhyn State University, Nizhyn, https://orcid.org/0000-0002-2194-134X

Puzyrov Volodymyr Yevhenovych Doctor of Physical and Mathematical Sciences, Professor, Professor of the Department of Informational Technologies, Physical, Mathematical and Economical Sciences, Mykola Gogol Nizhyn State University, Nizhyn, https://orcid.org/0000-0002-0522-8368

Termenzhy Daria Yevhenivna PhD in Pedagogical Sciences (theory and methodology of teaching mathematics), Associate Professor, Department of Higher and Applied Mathematics, Faculty of Finance and Digital Technology, State Tax University, Irpin, https://orcid.org/0000-0002-0539-5545

DESIGNING INFRASTRUCTURE FOR EFFECTIVE BLENDED LEARNING OF MATHEMATICS: LONGITUDINAL EXPERIMENTAL RESULTS

Abstract. The rapid digital transformation of higher education has intensified the need for effective pedagogical models capable of ensuring the continuity, flexibility, and quality of mathematics instruction. Blended learning, as an integrated approach combining face-to-face and online learning environments, has emerged as a promising solution; however, its effectiveness largely depends on the design of a coherent educational infrastructure.

This study aims to design and empirically validate an integrated infrastructure for blended learning in mathematics education, incorporating technological, pedagogical, and organizational components. The proposed model includes the use of a learning management system, an interactive mathematical portal, digital resources, and structured assessment tools, all aligned with a competency-based curriculum.

The research is based on a longitudinal experimental study conducted over five academic years (2013–2019) with mathematics students at a higher education institution. The study involved an experimental group exposed to the developed blended learning infrastructure and a control group taught using traditional methods. Data collection methods included pre- and post-tests assessing subject-specific and digital competencies, questionnaires, and graduate employment analysis.

The results demonstrate that students in the experimental group achieved significantly higher outcomes in both mathematical competencies and digital literacy. Statistical analysis (t-test) confirmed significant differences in four of six disciplines

at the 0.05 significance level. Additionally, the findings indicate improved student motivation, engagement, and professional readiness.

Despite limitations related to sample size and experimental design, the study provides evidence that a systematically designed blended learning infrastructure can enhance the development of key professional competencies in mathematics education. The results contribute to the theoretical and practical understanding of sustainable digital transformation in higher education and highlight prospects for further research in large-scale implementation and adaptive learning systems.

Keywords: educational infrastructure, blended learning, mathematics education, interactive teaching tools, competency-based approach, digital literacy, learning management system, Moodle, longitudinal study, higher education, learning analytics, student engagement, professional competencies, digital transformation, experimental study

Лосєва Наталія Миколаївна доктор педагогічних наук, професор, завідувач кафедри педагогіки, початкової освіти та освітнього менеджменту, Ніжинський державний університет імені Миколи Гоголя, м. Ніжин, https://orcid.org/0000-0002-2194-134X

Пузирьов Володимир Євгенович доктор фізико-математичних наук, професор, професор кафедри інформаційних технологій, фізико-математичних та економічних наук, Ніжинський державний університет імені Миколи Гоголя, м. Ніжин, https://orcid.org/0000-0002-0522-8368

Терменжи Дар'я Євгенівна кандидат педагогічних наук, доцент, доцент кафедри вищої та прикладної математики, Державний податковий університет, м. Ірпінь, https://orcid.org/0000-0002-0539-5545

ПРОЄКТУВАННЯ ІНФРАСТРУКТУРИ ДЛЯ ЕФЕКТИВНОГО ЗМІШАНОГО НАВЧАННЯ МАТЕМАТИКИ: РЕЗУЛЬТАТИ ДОВГОТРИВАЛОГО ЕКСПЕРИМЕНТАЛЬНОГО ДОСЛІДЖЕННЯ

Анотація. Стрімка цифрова трансформація вищої освіти посилила потребу в ефективних педагогічних моделях, здатних забезпечити безперервність, гнучкість і якість навчання математики. Змішане навчання, як інтегрований підхід, що поєднує очне та онлайн-навчальне середовище, постає перспективним рішенням; однак його ефективність значною мірою залежить від продуманого проєктування цілісної освітньої інфраструктури.

Метою цього дослідження є розроблення та емпірична перевірка інтегрованої інфраструктури змішаного навчання в математичній освіті, що охоплює технологічні, педагогічні та організаційні компоненти. Запропонована модель передбачає використання системи управління навчанням, інтерактивного

математичного порталу, цифрових ресурсів і структурованих інструментів оцінювання, узгоджених із компетентнісно орієнтованою навчальною програмою.

Дослідження базується на довгостроковому педагогічному експерименті, проведеному протягом п’яти навчальних років (2013–2019) зі студентами-математиками закладу вищої освіти. У дослідженні брали участь експериментальна група, яка навчалася в умовах розробленої інфраструктури змішаного навчання, та контрольна група, що навчалася за традиційною методикою. Для збору даних використовувалися вхідні та підсумкові тести для оцінювання предметних і цифрових компетентностей, анкетування та аналіз працевлаштування випускників.

Результати засвідчують, що студенти експериментальної групи продемонстрували значно вищі показники як з предметних компетентностей, так і з цифрової грамотності. Статистичний аналіз (t-критерій) підтвердив наявність значущих відмінностей у чотирьох із шести дисциплін на рівні значущості 0,05. Крім того, отримані дані свідчать про підвищення мотивації, залученості та професійної готовності студентів.

Попри обмеження, пов’язані з розміром вибірки та особливостями експериментального дизайну, дослідження надає переконливі докази того, що системно спроєктована інфраструктура змішаного навчання сприяє розвитку ключових професійних компетентностей у математичній освіті. Отримані результати роблять внесок у теоретичне та практичне осмислення сталої цифрової трансформації вищої освіти та окреслюють перспективи подальших досліджень у напрямі масштабування та впровадження адаптивних освітніх систем.

Ключові слова: змішане навчання, математична освіта, освітня інфраструктура, інтерактивні засоби навчання, компетентнісний підхід, цифрова грамотність, система управління навчанням, Moodle, довготривале дослідження, вища освіта, навчальна аналітика, залученість студентів, професійні компетентності, цифрова трансформація, експериментальне дослідження.

Problem statement. The rapid digital transformation of education has significantly reshaped the organization of the teaching and learning process, particularly in mathematically intensive disciplines. Blended learning, which purposefully integrates face-to-face instruction with digital educational environments, has emerged as a sustainable and pedagogically justified model for modern mathematics education. However, the effectiveness of blended learning depends not merely on the combination of instructional formats, but on the thoughtful design of its pedagogical, technological, and organizational infrastructure.

In mathematics education, the issue of infrastructure design is especially critical. Mathematics requires structured conceptual development, continuous formative assessment, visual representation of abstract concepts, and systematic feedback.

Without a coherent infrastructure that integrates learning management systems, digital mathematical tools, analytics mechanisms, and methodological support, blended learning risks becoming a fragmented practice rather than a holistic instructional model.

Our research highlights the growing importance of data-informed instructional design, adaptive learning pathways, and the integration of intelligent digital tools. Nevertheless, empirical evidence demonstrating the long-term impact of systematically designed blended learning infrastructures in mathematics remains limited. In particular, there is a need for longitudinal experimental studies that evaluate not only short-term academic performance, but also the development of higher-order mathematical competencies, learner autonomy, and sustained engagement.

Literature review. The issue of developing a modern scientific and educational infrastructure is not new to didactics; its various aspects have been examined by numerous scholars. A comprehensive study, *"A Comparative Study of National Infrastructures for Digital (Open) Educational Resources in Higher Education,"* [7] presents a comparative analysis of higher education systems in ten countries (Australia, Canada, China, Germany, Japan, South Africa, South Korea, Spain, Turkey, and the United States), focusing on policy frameworks, quality assurance mechanisms, and measures supporting the development of open educational resources (OER) infrastructure at the national level.

The article of Lithuanian scholars [9] *"Educational Infrastructure Using Virtualization Technologies: Experience at Kaunas University of Technology"* investigates the implementation of an original virtual desktop infrastructure (VDI) within the educational process. The authors conducted experiments involving network load monitoring (through direct observation and passive monitoring) to evaluate system performance and identify potential issues related to access to virtual resources for both students and instructors.

Additionally, the study *"The Hidden Architecture of Higher Education: Building a Big Data Infrastructure for the 'Smarter University'"* [14] examines the *Data Futures* project in the United Kingdom, which aims to develop a Big Data infrastructure for the higher education sector. The author analyzes how the use of data standards, dashboards, and visual analytics contributes to policy-driven market reforms and the reconceptualization of universities as "smart" digital institutions.

The study by Sorochan [23] provides a synthesis of knowledge regarding the essence of educational infrastructure, analyzes its components, and highlights its significance for ensuring the quality of education and institutional development.

Guribye and Lindström [3] conceptualize infrastructure as an integral element of the technological, material, and social conditions that underpin organized activities within institutional contexts, particularly in the sphere of teaching and learning at universities.

Consistent with the perspective advanced by Danish scholars [10], infrastructure is inherently relational in nature and, within higher education settings, is deliberately

designed to support instructional processes in accordance with institutional pedagogical frameworks and strategic objectives. Its effective configuration is instrumental in fostering education oriented toward the development of 21st-century competencies, including problem-solving, collaboration, and innovation [10].

Formulation of the article goals and objectives. The present study addresses this gap by designing and implementing an integrated infrastructure for blended mathematics learning and evaluating its effectiveness through a longitudinal experimental framework. The proposed model encompasses technological architecture, pedagogical strategies, assessment mechanisms, and learning analytics components aimed at supporting deep conceptual understanding and research-oriented mathematical thinking. The findings provide evidence-based insights into how systematically constructed blended learning environments can enhance the quality and sustainability of mathematics education over time.

Our research team possesses extensive and sustained experience in the application of educational technologies aimed at enhancing the quality of higher mathematics instruction in Ukraine. In 2011, we initiated a systematic research initiative focused on the study, design, and implementation of interactive teaching tools within several core mathematical disciplines, including *Analytical Geometry*, *Algebra and Geometry*, and *Introduction to Higher Mathematics* at the faculty level.

This initiative marked a significant milestone in our pedagogical development, as it reflected a strategic recognition of the pedagogical potential inherent in integrating high-quality face-to-face instruction with web-enhanced learning environments. The approach was grounded in the understanding that digital technologies, when methodologically aligned with disciplinary content and learning objectives, can substantially enrich students' conceptual understanding and engagement. The pedagogical experiment was conducted at Vasyl Stus Donetsk National University in a natural educational setting and was systematically designed, implemented, and monitored by our research team.

Presentation of the Main Research Materials. The pilot implementation of an educational interactive portal was initiated in the first-year *Analytical Geometry* course for mathematics students at the university during the Fall semester of 2012. This initiative was preceded by earlier research, the findings of which were partially reported in the author's PhD thesis [16] and conference talks [5; 11; 12], demonstrating the effectiveness of the proposed methodology in enhancing teaching–learning interactions, increasing student engagement and commitment, and fostering higher levels of motivation.

Building on these results, a comprehensive experimental study was undertaken with a focus group, encompassing the entire period of their academic training (Bachelor's and Master's levels). The study represents an alternative approach to the organization of the teaching and learning process in mathematics within a higher education context. It was implemented over an extended period, spanning the 2013/2014 to 2018/2019 academic years.

The primary phase of the experimental research has been completed. However, longitudinal follow-up observations of the graduates are still ongoing as of 2026, the results of which are presented in the subsequent sections.

It should be noted that the initial cohort comprised 38 participants. However, in 2014, due to the complex socio-political situation in eastern Ukraine, the University was relocated from Donetsk to Vinnytsia. As a result, a number of students transferred to other higher education institutions across the country. Consequently, the study was ultimately limited to the experience of fourteen students who remained enrolled and successfully completed the programme. Despite the reduced sample size, the research project was continued.

The final sample consisted of 14 students admitted in the 2013/2014 academic year, specializing in Mathematics. The participants were aged between 17 and 22 years. The selection criteria included students' expressed interest in participation as well as their access to the necessary technological resources for learning (e.g., laptops, smartphones, personal computers, webcams, etc.).

Given the limited sample size ($n = 14$), it was deemed methodologically appropriate to designate as a control group a preceding cohort of Mathematics students (enrolled in the 2012/2013 academic year) who remained at the University and completed the full cycle of mathematical courses through traditional instructional approaches.

Over the course of five academic years, six mathematical disciplines were delivered: *Analytical Geometry* (2013/2014), *Mathematical Logic* (2014/2015), *Differential Geometry* (2014/2015), *Methodology of Teaching Mathematics* (2015/2016), *History of Mathematics* (2016/2017), and *IT in Teaching Mathematics* (2017/2018) (see Fig. 1).

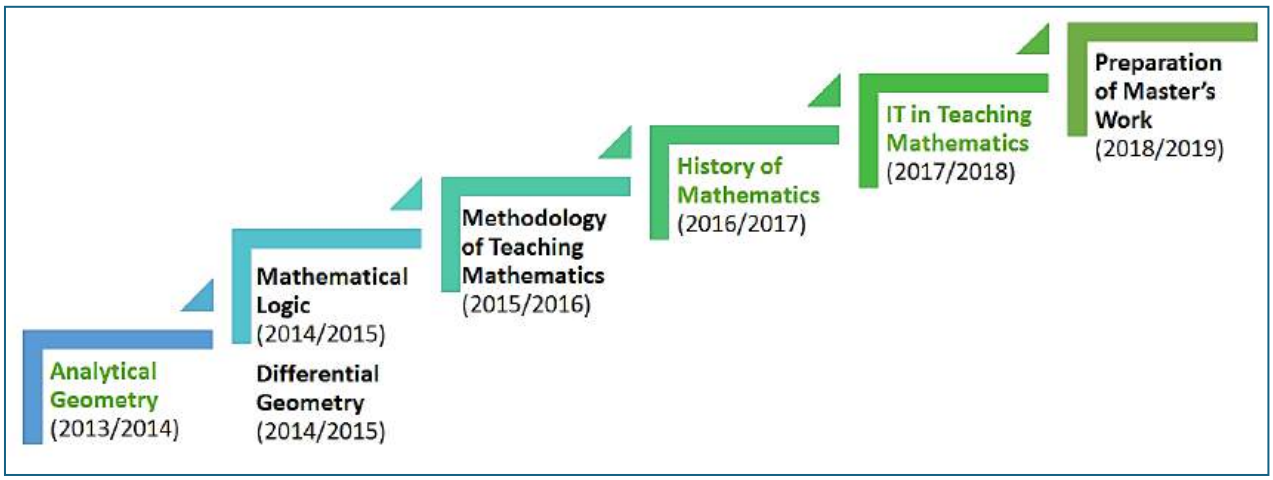


Fig. 1 List of mathematical courses taught within the framework of the experiment (from 2013/2014 to 2018/2019 academic years)

The aforementioned courses, along with the additional course *"Preparation of Master's Work,"* were delivered using interactive teaching tools within a blended

learning framework as the overarching pedagogical strategy, incorporating, in particular, the flipped classroom model. In contrast, the remaining courses within the curriculum were taught using traditional instructional methods.

Five of these courses were part of the Bachelor's degree programme, while two (including the additional course) belonged to the Master's degree programme. All courses constitute standard (normative) one- and two-semester mathematical disciplines offered to Mathematics students at Vasyl Stus Donetsk National University.

Methodology and background of the study. The methodological framework of the study involved the integration of interactive teaching tools to support blended learning within a competency-based mathematics curriculum. The key conceptual foundations of this approach are briefly outlined below.

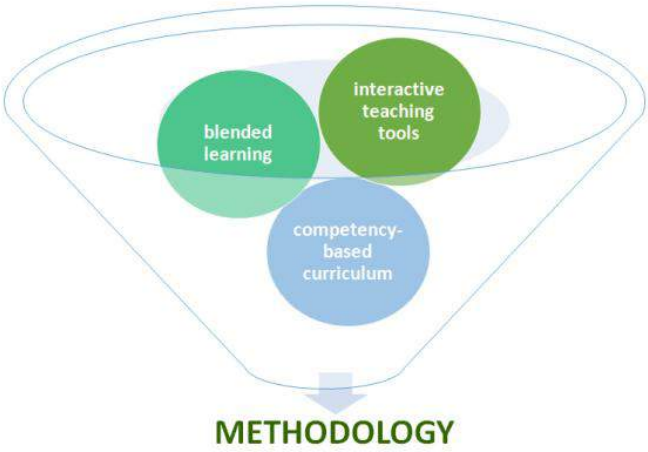


Fig. 2. Methodology and background of the study

Despite its widespread use in higher education, there is no single universally accepted definition of the term *"interactive teaching tool."* In the scholarly literature, it is often used interchangeably with related concepts such as *digital educational tools*, *interactive learning materials*, *web-based teaching tools*, *digital educational resources*, or *online learning tools* [21]

Within the framework of this study, interactive teaching tools are conceptualized as learning resources that emphasize active student interaction and facilitate the management of educational activities.

These tools are designed to support the achievement of specific learning outcomes and may consist of single- or multi-page resources incorporating various modalities, including text, images, audio, and video (e.g., screencasts and animations), as well as self-assessment components and other interactive tasks.

The integration of interactive tools into the educational process leads to a transformation of the traditional didactic system (Fig. 3): new types of learning activities emerge, various forms of instructional interactivity become feasible, predominantly interactive teaching methods are employed, and the effectiveness of both synchronous and asynchronous modes of learning is enhanced [16].

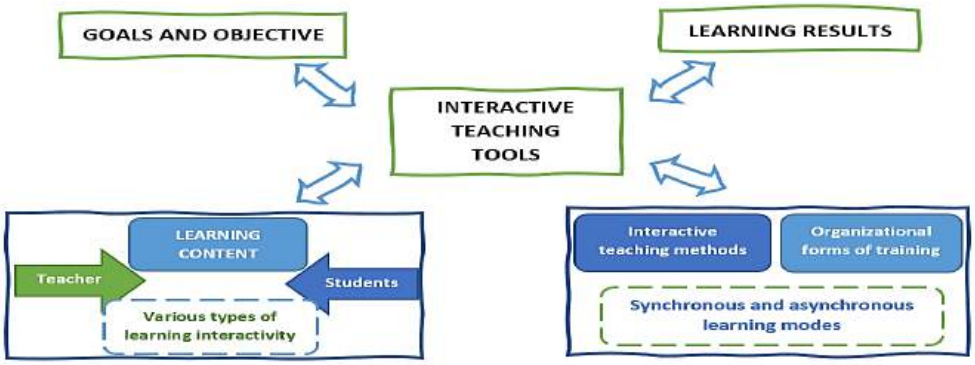


Fig. 3. Structure of the didactic system with the use of interactive tools

The introduction of interactive tools in the study of mathematical disciplines enables new types of learning activities, including the collection, accumulation, storage, and mathematical processing of information about the objects, phenomena, and processes under investigation; the transmission of substantial volumes of educational information presented in diverse formats; and the manipulation of on-screen mathematical models representing various real-world objects, phenomena, and processes [20]. The article by Ukrainian scholars [21] examines approaches to the individualization of teaching analytical geometry through the use of interactive tools. It highlights the application of various instruments (such as graphical editors and computer algebra systems) to enhance the understanding of subject matter, promote students' independent work, and implement a learner-centered approach.

Blended learning has become critically important in Ukrainian education today, as it ensures the continuity, flexibility, and resilience of the learning process under conditions of ongoing socio-political instability and digital transformation [8]. It is **"**a learning that combines characteristics of both traditional and online education in integrated model, and gain the maximum benefit from the available techniques apiece" [2]

By using the term competency we will refer to the definition of competencies (Weinert, 2001) as "the cognitive abilities and skills possessed by or able to be learned by individuals that enable them to solve particular problems, as well as the motivational, volitional and social readiness and capacity to use the solutions successfully and responsibly in variable situations"[13]

In accordance with the competency-based approach, a competency-oriented curriculum for Mathematics students at both the Bachelor's and Master's levels was developed in 2013, based on the national educational standards established by the Ministry of Education and Science of Ukraine. In our study, we adopted the classification of competencies proposed by Ukrainian researchers [17], which includes key, professional, and subject-specific competencies. Key competencies manifest not only in the resolution of professional tasks but also in addressing challenges beyond one's field of specialization [18]. Professional competencies correspond to the requirements for a specialist's professional preparedness and determine their ability to act effectively in accordance with professional standards, to solve tasks and problems

within a specific field of activity in a methodologically structured and autonomous manner, and to evaluate the outcomes of such activity [22]. In addition to procedural, logical, methodological, methodological, research, and technological competencies (Rakov, 2005), educators also identify a "visual sub-competence" [19] as part of the professional competencies of mathematicians and mathematics teachers, which is defined as an integrative ability of a teacher to apply visual tools in order to facilitate students' perception and comprehension of mathematical concepts.

Subject (discipline) competencies are understood as those competencies acquired by students through the study of a particular subject within a defined academic year or stage of education [17].

Ukrainian scholars [18] have identified the following core components of subject-specific competencies: knowledge, skills, abilities, and attitudes. In our view, the structure of subject-specific competencies should also be extended to include an additional, equally important component – namely, the presence of relevant experience (See Fig 4).

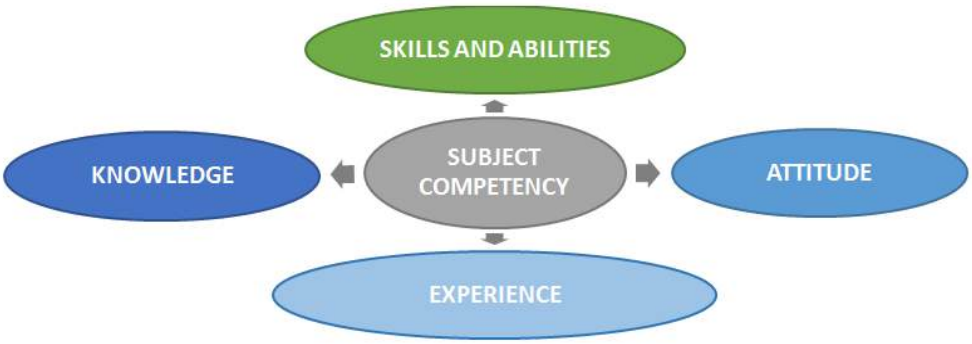


Fig. 4. The structure of subject-specific competency

Finally, the principal aim of this experimental study was to investigate whether the implementation of the proposed blended learning infrastructure would enhance the development of students' subject-specific and IT competencies, as well as contribute to their preparedness for future professional practice.

Within the framework of the empirical study, students engaged with distance learning courses delivered via the Moodle platform, developed by the research team. All courses were designed and implemented in the national language, Ukrainian [6].

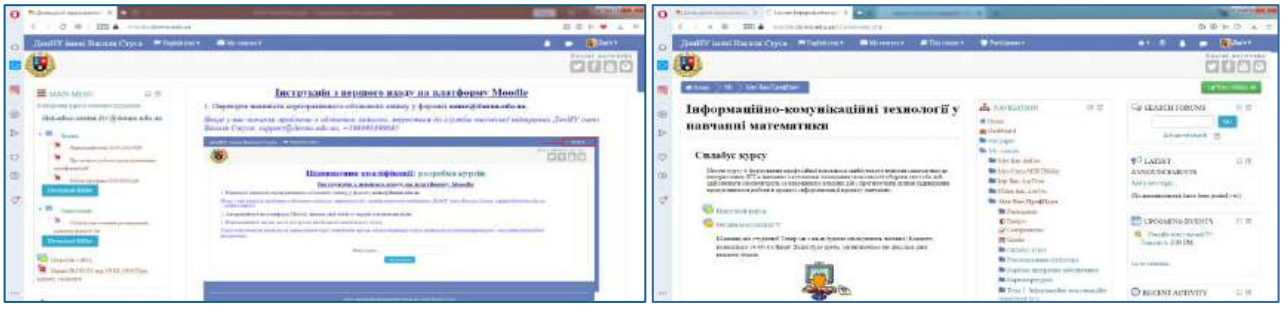


Fig.5. Course on Moodle platform

As noted previously, the core component supporting both synchronous and asynchronous online elements across the six disciplines is the set of courses developed by our research team within the Moodle platform. Through these online courses, students are provided with access to videolectures, tools for monitoring assignments and academic progress, opportunities for interaction with instructors and peers, as well as a wide range of supplementary materials, including PowerPoint presentations, SmartBoard slide lectures, mathematical software packages, and research articles.

The Moodle-based courses are structured to include the following components:

- Syllabus, outlining the content of each discipline within the mathematics curriculum;
- Tutorial slide lectures, accompanied by interactive exercises performed online, which provide automated quantitative results, immediate feedback for each task, and model solutions;
- Video of lectures, available for download;
- Diagnostic online tests, offering instant results and feedback to support students' self-assessment of their performance;
- Links to external web resources, facilitating deeper exploration of mathematical topics;
- Additional tasks designed for high-achieving students;
- Online quizzes and surveys, including multiple-choice, true/false, and matching formats, aimed at fostering students' self-regulated learning and improving performance outcomes;
- A repository of students' research projects;
- Discussion forums, enabling academic communication and collaboration.

Overall, this structured digital environment serves as an integral component of the blended learning model, supporting both instructional delivery and the development of students' autonomous learning skills [15].

At the initial stage of the blended learning, students participated in face-to-face sessions held in a computer laboratory, during which they engaged in induction activities related to the Moodle course environment, including navigation, access to learning resources, participation in forum discussions, use of the online consultation module, and involvement in interactive mathematical activities. [11]

According to experts, effective student engagement in a blended learning mathematics course should encompass a balanced integration of individual and collaborative work, as well as formal and supplementary learning activities and resources, in order to support the achievement of intended learning outcomes [8].

Drawing on our experience, we consider it essential to engage students with contemporary research developments in mathematics [1] through activities such as analytical work with scholarly texts (e.g., structured literature reviews), thereby fostering their academic literacy and research competencies.

The implementation of interdisciplinary connections in mathematics requires their integration into content, methods, and instructional formats (e.g., integrated lectures and elective courses), and although this poses a complex pedagogical

challenge often necessitating collaborative effort, it effectively enhances students' competencies, motivation, and holistic understanding by bridging disciplinary boundaries and reducing fragmentation of knowledge [4].

Across all courses, academic staff is required to provide tutorial support; however, this may present challenges when students are studying remotely. To address this, a range of online modalities is employed to facilitate both individual and group consultations in real time, including online chat, virtual classrooms, and telephone or teleconferencing [6].

Several results of the study. The experimental testing procedure comprised five components, including the use of an electronic survey administered via the Google Forms platform. At the initial stage of the study, a series of pre-tests was conducted, including assessments of subject-specific competencies (across six disciplines), digital literacy, and intellectual characteristics (e.g., intellectual lability and ambition). The validity and reliability of these instruments were established. According to the results of the t-test, no statistically significant differences were observed between the experimental and control groups in the pre-tests or intellectual assessments.

Throughout the study, students in the experimental group completed a number of questionnaires (e.g., *"My Motivation," "Features of Using the Moodle Course"*), in which they evaluated various aspects of the learning experience using a five-point Likert scale. Overall, students expressed positive attitudes toward both the experimental design and the associated learning experience.

At the final stage of the study, the following instruments were administered:

- post-tests in mathematics (subject-specific competencies) and digital literacy;
- questionnaires (e.g., *"My Learning Outcomes"*);
- interviews focusing on graduate employment outcomes (*"Alumni Job Placement"*).

In addition, anonymous surveys were conducted after each mathematical course upon completion of the final examination. The results indicate that students in the experimental group demonstrated higher learning outcomes compared to those in the control group. According to the T-test, statistically significant differences (at the 0.05 significance level) were identified in four of the six courses (*Analytical Geometry*, *Differential Geometry*, *Methodology of Teaching Mathematics*, and *History of Mathematics*).

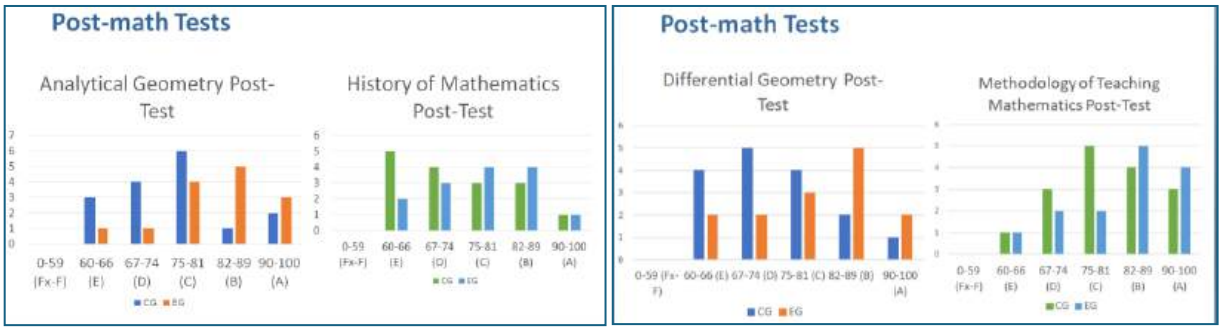


Fig.6. Results of post-math tests

In comparison with the control group, the experimental group demonstrated superior performance in the Digital Literacy post-test: over 20% of students achieved the highest (expert) level, 28% attained a high level, 36% a moderate level, and only two students remained at the basic level. According to the results of the t-test, the difference between the experimental and control groups was statistically significant at the 0.1 level of significance.

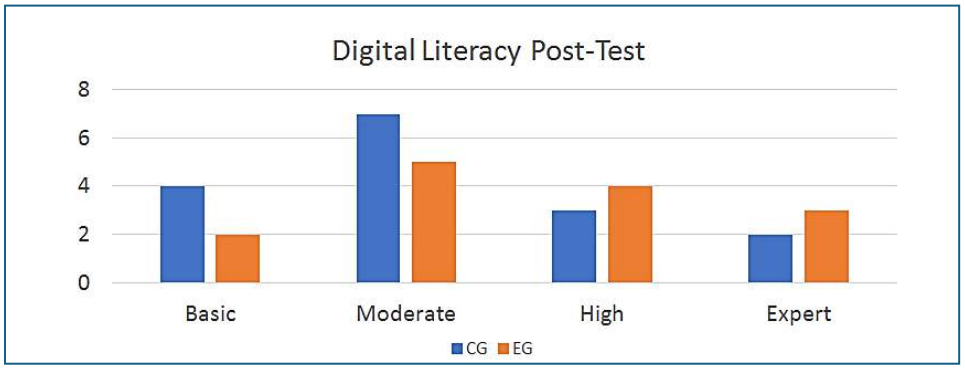


Fig.7. Results of Digital Literacy post-test

The results of the graduate interviews conducted in 2020 (*"Alumni Job Placement"*) yielded notable findings. The analysis indicates that more than one-third of the experimental group are employed within their field of specialization, including positions as a mathematician in a research institution (1) and as teachers of mathematics and computer science (4), whereas in the control group only 25% of graduates are employed in mathematics-related professions.

Furthermore, 43% of the experimental group and 38% of the control group are engaged in related professional fields (such as business and financial analysis, mobile application development, and software engineering). Only one alumni from each group pursued further studies at the postgraduate level. At the same time, two graduates from the experimental group and five from the control group are not currently applying their formal education in their professional activities.

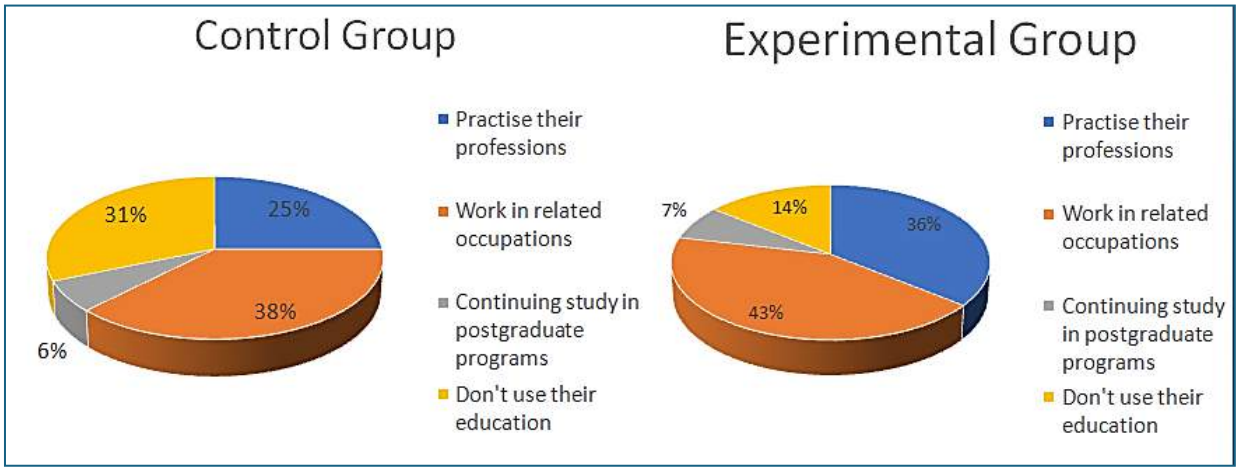


Fig.8. Results of *Alumni Job Placement test*

It should be noted, then for more than five years (from 2020 till present), we have been systematically monitoring the career trajectories of our graduates. This activity has evolved beyond a purely experimental or statistical endeavor into a reflective analytical instrument, enabling us – within new institutional contexts, as both researchers and institutions evolve – to introduce evidence-based adjustments to educational programmes, enhance the professional preparedness of mathematics students, and strengthen the reputation of higher education institutions. In addition to active data collection methods, we have incorporated "passive" data collection approaches, including the analysis of professional networks such as LinkedIn and the documented career achievements of our alumni.

We also seek to support and sustain the professional value of our graduates by engaging them in academic and professional communities: inviting them to participate in networking events, encouraging their involvement in scientific and practical conferences, and collaborating with them to provide information on job vacancies and internship opportunities. Notably, in a nationwide mathematics video competition organized by our team, a prize-winning participant was mentored by a mathematics teacher who had previously belonged to the experimental group, which further demonstrates the long-term impact of the study.

Furthermore, graduates are actively involved as experts (stakeholders) in the evaluation and refinement of curricula and course syllabi. We also invite our most successful alumni to deliver guest lecturers to our students (e.g., within the course *"Introduction to the Profession"*), including not only those employed directly in mathematics-related fields, but also those working in adjacent domains, such as IT project management. This approach allows us to demonstrate the broader applicability of mathematical education, particularly in terms of transferable (soft) skills and interdisciplinary mobility.

Conclusions and prospects for further research. The integration of interactive teaching tools within a blended learning framework encourages both students and instructors to reconsider traditional educational infrastructure. From the lecturer's perspective, the transition to blended learning may initially present challenges, as it requires a substantial shift in professional roles – from knowledge transmission to facilitation of learning [5]. These challenges are further compounded by the increased time investment needed for course design, including the identification and/or development of high-quality digital resources and interactive learning activities that promote student engagement and active participation. Nevertheless, the advantages of this instructional model are considered to outweigh the associated challenges and additional workload.

It should be acknowledged that the present study has certain limitations. First, the sample size is relatively small. Second, a more robust design would involve a comparison between a cohort exposed to the proposed methodology across all mathematical disciplines and a cohort taught exclusively through traditional methods. However, such an approach would require a different experimental design and lies beyond the scope of this research.

In conclusion, the findings of this study indicate that the proposed learning infrastructure contributes to the development of professional competencies in mathematics students, including digital competence, and enhances their motivation to engage with the discipline.

References:

1. Awrejcewicz, J., Cheaib, A., Losyeva, N., Puzyrov, V. (2020). Responses of a two degrees-of-freedom system with uncertain parameters in the vicinity of resonance 1:1. Nonlinear Dynamics, 2020, 101, pp. 85–106. https://doi.org/10.1007/s11071-020-05710-7

2. Dziuban, C.D., Hartman, J.L., Moskal, P.D. (2004) Blended Learning. EDUCAUSE Center for Applied Research Research Bulletin 2004(7), 1–12 (March 2004), URL https://www.educause.edu/~/media/files/library/2004/3/erb0407-pdf.pdf?la=en

3. Guribye, F.& Lindström, B. (2009). Infrastructures for learning and networked tools: The introduction of a new tool in an inter-organisational network. In: Analysing Networked Learning Practices in Higher Education and Continuing Professional Development. Brill, 2009. https://doi.org/10.1163/9789460910074_007

4. Losyeva, N. & Puzyrov, V. (2023). Mizhdystsyplinarnyi kontekst matematychnoi osvity [Interdisciplinary context of mathematics education]. In: The 9th International Scientific and Practical Conference "Modern Problems of Science, Education and Society". Kyiv, Ukraine: SPC "Sciconf.com.ua", 2023, pp. 529–535. [in Ukrainian]

5. Losyeva, N. & Termenzhy, D. (2015). Blended Learning in Action: Up-to-date teaching mathematics. In: Conference Proceedings. Abstracts. X International GUIDE Conference "Optimizing Higher Education for the Professional Student: A Balance of Flexibility, Quality and Cultural Sensitivity". Vienna, Austria, September 16–18, 2015, p. 35.

6. Losyeva, N. &Termenzhy, D. (2016). Distance technologies in action: E-learning in exile (the experience of Donetsk National University, Ukraine). In: Educación y Sociedad en Red. Los desafíos de la era digital. Buenos Aires: USAL, 2016. Available at: http://p3.usal.edu.ar/index.php/supsignosead/issue/current

7. Marin, V. et al. (2020). A Comparative Study of National Infrastructures for Digital (Open) Educational Resources in Higher Education. Open Praxis, 2020, vol. 12, issue 2, pp. 241–256.

8. Mintii, I.S. (2023) Blended learning: definition, concept, and relevance. *Educational Dimension* [Online], 8, pp.85–111. URL: https://doi.org/10.31812/ed.539

9. Miseviciene, R., Ambraziene, D., Tuminauskas, R., Pazereckas, N. (2012) Educational Infrastructure Using Virtualization Technologies: Experience at Kaunas University of Technology. Informatics in Education, 2012, vol. 11, no. 2, pp. 227–240.

10. Tabo, G.O., Dirckinck-Holmfeld, L. & Bygholm, A. (2025) Transforming Higher Education for Community Development. Developing Infrastructures for Learning: Perspectives and Proposals in Design of New Practices. Chapter 15, 2025. https://doi.org/10.1163/9789004731585_015

11. Termenzhy, D. (2016) Some ways for implementation of blended learning of mathematics: The author's experience. In: 7th European Congress of Mathematics (7ECM-2016): Conference Scientific Program. Berlin, Germany: Technische Universität Berlin, July 18–22, 2016, p. 76.

12. Termenzhy, D. & Losyeva, N. (2018). Prospect of implementing blended learning of mathematics in higher education: A case study of Vasyl Stus Donetsk National University. In: International Conference on Mathematics, Informatics and Informational Technologies (MITI-2018). Balti, Moldova, April 19–21, 2018, pp. 215–217.

13. Weinert, F. E. (2001) *Concept of competence: a conceptual clarification*. In D. S. Rychen, & L. H. Salganik (Eds.), Defining and selecting key competencies. 2001(pp. 45e66).

14. Williamson, B. (2018). The hidden architecture of higher education: Building a big data infrastructure for the 'smarter university'. International Journal of Educational Technology in Higher Education, 2018. https://doi.org/10.1186/s41239-018-0094-1

15. Zhenxiong, L., Slyvka, L., Olynets, T., Termenzhy, D., Huz, V. (2025) The Use of Educational Technologies in Personalized Learning of Primary School Students. International Electronic Journal of Elementary Education, 2025, 18(1). Available at: https://iejee.com/index.php/IEJEE/article/view/2598

16. Hubar, D.Ye. (2013). *Metodyka stvorennia i zastosuvannia interaktyvnykh zasobiv navchannia studentiv klasychnoho universytetu analitychnoi heometrii* [Methodology of creating and applying interactive learning tools for students of analytical geometry in a classical university] (Candidate's thesis). Donetsk National University, Donetsk. [in Ukrainian]

17. Ovcharuk, O.V. (Ed.). (2004). *Kompetentnisnyi pidkhid u suchasnii osviti: svitovyi dosvid ta ukrainski perspektyvy* [Competency-based approach in modern education: Global experience and Ukrainian perspectives]. K.I.S. [in Ukrainian]

18. Shynkaruk, V.D. (Ed.). (2008). *Kompleks normatyvnykh dokumentiv dlia rozroblennia skladovykh systemy haluzevykh standartiv vyshchoi osvity* [A set of regulatory documents for developing components of sectoral higher education standards]. [in Ukrainian]

19. Losyeva, N., & Horoshko, O. (2025). Pedahohichna diialnist vykladachiv universytetiv u konteksti formuvannia ta otsiniuvannia vizualnoi subkompetentnosti maibutnikh uchyteliv matematyky. *Naukovi zapysky NDU: Psykholoho-pedahohichni nauky*, (1), 178–186. [in Ukrainian]

20. Losyeva, N. M., & Hubar, D. Ye. (2014). *Analitychna heometriia v interaktyvnii formi: praktychnyi kurs* [Analytical geometry in an interactive form: Practical course]. Kafedra. [in Ukrainian]

21. Losyeva, N. M., & Hubar, D. Ye. (2012). Indyvidualizovane navchannia analitychnoi heometrii z vykorystanniam interaktyvnykh zasobiv. *Vyshcha osvita Ukrainy*, (1, Suppl. 3, Vol. III), 360–366. [in Ukrainian]

22. Rakov, S.A. (2005). *Matematychna osvita: kompetentnisnyi pidkhid z vykorystanniam IKT* [Mathematics education: A competency-based approach using ICT]. Fakt. [in Ukrainian]

23. Sorochan, T.M. (2015) Infrastruktura navchalnoho zakladu v teorii ta praktytsi upravlinnia osvitoiu [Infrastructure of an educational institution in the theory and practice of education management]. Problemy osvity, 2015, no. 2 (83), pp. 180–185. [in Ukrainian]

Література:

1. Awrejcewicz Jan, Cheaib Akram, Losyeva Nataliya, Puzyrov Volodymyr. Responses of a two degrees-of-freedom system with uncertain parameters in the vicinity of resonance 1:1 // Nonlinear Dynamics-2020, 101, P.85–106. doi.org/10.1007/s11071-020-05710-7

2. Dziuban C.D., Hartman J.L., Moskal P.D. Blended Learning. EDUCAUSE Center for Applied Research Research Bulletin 2004(7), 1–12 (March 2004), URL https://www.educause.edu/~/media/files/library/2004/3/erb0407-pdf.pdf?la=en

3. Guribye, F., & Lindström, B. Infrastructures for learning and networked tools: The introduction of a new tool in an inter-organisational network. In Analysing networked learning practices in Higher Education and continuing professional development. Brill. 2009. https://doi.org/10.1163/9789460910074_007.

4. Losyeva N., Puzyrov V. Міждисциплінарний контекст математичної освіти // The 9th International scientific and practical conference «Modern problems of science, education and society» SPC «Sciconf. com. ua», Kyiv, Ukraine. 2023, P.529-535.

5. Losyeva N., Termenzhy D. Blended Learning in Action: Up-to-date teaching mathematics. Conference Proceedings. Abstracts. X International GUIDE Conference «Optimizing Higher

Education for the Professional Student: A balance of flexibility, quality and cultural sensitivity». Vienna, Austria. September 16-18, 2015. P. 35.

6. Losyewa N. Termenzhy D. Distance technologies in action: E-learning in exile (the experience of Donetsk National University, Ukraine) / Educación y Sociedad en Red. Los desafíos de la era digital. USAL, Buenos Aires, 2016. URL: http://p3.usal.edu.ar/index.php/supsignosead/issue/current

7. Marin V. et al. A Comparative Study of National Infrastructures for Digital (Open) Educational Resources in Higher Education Open Praxis, vol. 12 issue 2, April–June 2020, pp. 241–256.

8. Mintii I.S., Blended learning: definition, concept, and relevance. Educational Dimension [Online], 8, pp.85–111. URL: https://doi.org/10.31812/ed.539

9. Misevicien R., Ambrazien D., Tuminauskas R., Pažereckas N. Educational Infrastructure Using Virtualization Technologies: Experience at Kaunas University of Technology Informatics in Education, 2012, Vol. 11, No. 2, 227–240.

10. Tabo G. O., Dirckinck-Holmfeld L., Bygholm A. Transforming Higher Education for Community Development. *Developing Infrastructures for Learning: Perspectives and Proposals in Design of New Practices*. Chapter 15 June 2025 DOI: 10.1163/9789004731585_015

11. Termenzhy D. Some ways for implementation the blended learning of mathematics: The author's experience/ 7th European Congress of Mathematics (7ECM-2016): Conference Scientific Program. July 18-22, 2016. Technische Universität Berlin, Berlin, Germany. P. 76.

12. Termenzhy D., Losyeva N. Prospect of implementing a blended learning of mathematics in higher education: a case study of Vasyl Stus Donetsk National University // International Conference on mathematics, informatics and informational technologies (MITI-2018). April 19-21, 2018. Balti, Moldova. P. 215-217.

13. Weinert F. E. Concept of competence: a conceptual clarification. In D. S. Rychen, & L. H. Salganik (Eds.), Defining and selecting key competencies. 2001(pp. 45e66).

14. Williamson B. The hidden architecture of higher education: building a big data infrastructure for the 'smarter university' International Journal of Educational Technology in Higher Education (2018) DOI 10.1186/s41239-018-0094-1.

15. Zhenxiong L., Slyvka L., Olynets T., Termenzhy D., & Huz V. The Use of Educational Technologies in Personalized Learning of Primary School Students. *International Electronic Journal of Elementary Education*, *18*(1). 2025 URL: https://iejee.com/index.php/IEJEE/article/view/2598

16. *Губар Д. Є. Методика створення* і *застосування інтерактивних засобів навчання студентів класичного університету аналітичної геометрії* : *дис….канд. пед. наук 13.00.02. «Теорія* та *методика навчання* (*математика)*» Донецький національний *університет*. Донецьк, 2013. 374 с.

17. Компетентнісний підхід у сучасній освіті: світовий досвід та українські перспективи: Бібліотека з освітньої політики / Під заг. ред. О.В. Овчарук. К. : К.І.С., 2004. 112с.

18. Комплекс нормативних документів для розроблення складових системи галузевих стандартів вищої освіти // За загальною редакцією В.Д. Шинкарука. К., 2008. 68 с.

19. Лосєва Н., Горошко О. Педагогічна діяльність викладачів університетів у контексті формування та оцінювання візуальної субкомпетентності майбутніх учителів математики // Наукові записки НДУ: Психолого-педагогічні науки. Видавництво НДУ ім. М. Гоголя, 2025. № 1, С.178-186.

20. Лосєва Н. М., Губар Д. Є. Аналітична геометрія в інтерактивній формі: практичний курс: навч. посіб. для студентів. К.: Кафедра, 2014. 236 с.

21. Лосєва, Н.М., Губар, Д.Є. Індивідуалізоване навчання аналітичної геометрії з використанням інтерактивних засобів. Вища освіта України. Дод. 3 до №1, Том ІІІ. Темат. вип. «Міжнародні Челпановські психолого-педагогічні читання». 2012. С. 360-366.

22. Раков С.А. Математична освіта: компетентнісний підхід з використанням ІКТ: Монографія. Х.:Факт, 2005. 360 с.

23. Сорочан Т.М. *Інфраструктура навчального закладу* в *теорії* та *практиці управління освітою* // Проблеми *освіти*. № 2 (83). 2015. С. 180-185.

Дата першого надходження статті до видання: 23.04.2026
Дата прийняття статті до друку після рецензування: 07.05.2026