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Integration of Digital and Computer Technologies into Teaching Mathematical Analysis: Innovative Competence-Based Approaches and Prospects for Development

دمج التقنيات الرقمية والحاسوبية في تدريس التحليل الرياضي :مناهج مبتكرة قائمة على الكفاءة و آفاق التطوير

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Abstract: The study aimed to explore correlations between digital activity, student satisfaction, and assimilation of mathematical analysis content in Kyrgyzstan. The theoretical and empirical study was conducted between January and April 2025 at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov. The sample included 130 respondents, including 112 undergraduate and graduate students majoring in mathematics and computer science, and 18 teachers of relevant disciplines who participated in the survey before and after completing a digital module implemented using the GeoGebra, Desmos, Moodle, and Wolfram Mathematica platforms. A theoretical analysis of educational programmes and regulatory documents governing digital integration was also conducted. The results showed an increase in the proportion of highly motivated students from 30% to 60%, a decrease in the proportion of low-motivation students from 25% to 10%, and an increase in satisfaction with digital solutions to 62.5%. Statistical analysis confirmed a significant positive correlation (ρ=0.47) between the regularity of digital tool use and self-assessment of learning outcomes. Institutional differences in approaches were identified: at Kyrgyz State University named after I. Arabaev, the emphasis was on visualisation and methodological support, while at Jalal-Abad State University named after B. Osmonov, the emphasis was on functionality and analytical accuracy. The data obtained confirm the didactic significance of digital solutions for adapting course content to the specifics of training, increasing learning motivation, and developing functional mathematical literacy. The results can be used to update educational standards, develop digital training modules, and improve the quality of training for mathematics teachers in the context of digitalisation.

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المستخلص: هدفت هذه الدراسة إلى استكشاف العلاقة بين النشاط الرقمي ورضا الطلاب واستيعابهم لمحتوى التحليل الرياضي في قيرغيزستان .أُجريت الدراسة النظرية والتجريبية بين يناير وأبريل 2025 في جامعة قيرغيزستان الحكومية التي تحمل اسم إ .أرابايف وجامعة جلال آباد الحكومية التي تحمل اسم ب .عثمانوف .شملت العينة 130 مشاركًا، من بينهم 112 طالباً وطالبة في مرحلتي البكالوريوس والدراسات العليا متخصصين في الرياضيات وعلوم الحاسوب، و 18مدرساً من التخصصات ذات الصلة، شاركوا في الاستبيان قبل وبعد إكمال وحدة رقمية مُنفذة باستخدام منصات GeoGebra و Desmosو Moodleو .Wolfram Mathematicaكما أُجري تحليل نظري للبرامج التعليمية والوثائق التنظيمية التي تُنظم التكامل الرقمي. أظهرت النتائج زيادة في نسبة الطلاب ذوي الدافعية العالية من 30% إلى60%، وانخفاضًا في نسبة الطلاب ذوي الدافعية المنخفضة من 25% إلى10%، وزيادة في الرضا عن الحلول الرقمية إلى62.5% ، وأكد التحليل الإحصائي وجود ارتباط إيجابي قوي (ρ=0.47) بين انتظام استخدام الأدوات الرقمية والتقييم الذاتي لنتائج التعلم .وتم رصد اختلافات مؤسسية في المناهج المتبعة: ففي جامعة قيرغيزستان الحكومية التي تحمل اسم إ .أرابايف، كان التركيز على التصور البصري والدعم المنهجي، بينما في جامعة جلال آباد الحكومية التي تحمل اسم ب .عثمانوف، كان التركيز على الوظائف والدقة التحليلية .وتؤكد البيانات التي تم الحصول عليها الأهمية التعليمية للحلول الرقمية في تكييف محتوى المقرر الدراسي مع خصوصيات التدريب، وزيادة دافعية التعلم، وتنمية مهارات الرياضيات الوظيفية. ويمكن الاستفادة من هذه النتائج في تحديث المعايير التعليمية، وتطوير وحدات التدريب الرقمي، وتحسين جودة تدريب معلمي الرياضيات في سياق التحول الرقم..

الكلمات المفتاحية: التغيرات التحفيزية، الأساليب التفاعلية، النشاط الرقمي للطلاب، تصور البيئة الإلكترونية، التقنيات التعليمية.

1 INTRODUCTION

Since 2020, there has been active development of digital practices in mathematics education, which has been particularly evident in the teaching of mathematical analysis courses. Digital platforms such as GeoGebra, Moodle, Desmos, and Wolfram Mathematica have been increasingly integrated into the learning process to enhance visualisation, interactivity, and adaptability in teaching. The spread of such solutions was particularly intense during the COVID-19 pandemic, when the educational process moved online on a massive scale. This transition revealed both the potential of digital tools and their limitations in the context of remote interaction. However, despite the widespread adoption of digital solutions, the question of their real impact on motivation, satisfaction and learning outcomes remains relevant. There is still insufficient research on how such platforms are perceived by the direct participants in the educational process, teachers and students, and what pedagogical consequences are associated with digital activity.

The topic of digital transformation in mathematics education has been partially covered in several modern studies. For example, Cirneanu and Moldoveanu (2024) focused on the potential of digital platforms for developing integrated competencies and organizing thematically linked educational content. Ulpetbaeva (2025) investigated the specifics of using information technologies in teaching mathematics to economics students, emphasizing the need for methodological adaptation, but without mentioning the aspect of motivation. In turn, Wang (2025) analyzed the use of digital media technologies

in colleges, where the main focus is on the technical aspects of visualization and automation, but not on pedagogical interaction.

Kobernik (2025) demonstrated new approaches to developing the mathematical competence of future elementary school teachers, incorporating digital platforms as supporting tools, but did not assess the impact of such solutions within the higher education system. However, Gungordu and Yildirim (2025) focused their study on forming an online professional community of teachers to enhance their digital literacy, but no empirical study of student perceptions was conducted. Weberg et al. (2020) presented a Swedish case study that highlighted the challenges of institutional implementation of digital solutions, but no quantitative analysis of performance indicators was conducted. Finally, Suranchieva et al. (2023) developed a digital teaching system for discrete mathematics for future computer science teachers, emphasizing content structure but not investigating the link between digital practices and motivation to learn. Krpets et al. (2024) analyzed the portfolios of students specializing in pedagogy and studying the fundamentals of mathematics education. The study showed that visual and interactive digital tools were predominant, although the empirical component of the study was limited to identifying learning artifacts without linking them to motivational factors or cognitive indicators.

The work by Saata et al. (2024) provided a methodologically systematic review, and digital platforms were categorized by type of interaction, nature of tasks, and level of complexity. However, despite the wide variety of sources, no analysis was conducted of differences in how students and instructors perceive digital solutions, nor were local characteristics of technology implementation in Central Asian countries taken into account. The study by Tang et al. (2021) focused on the implementation of information technologies in the discipline of mathematical analysis and outlined the stages of planning and implementing blended learning. The study was quite practical, but the authors did not provide generalized statistical data on participant satisfaction levels or the impact of the digital component on learning outcomes. Siller et al. (2023) explored the educational potential of digital modeling and discussed the benefits of digitally representing mathematical processes. The study also noted issues of cognitive overload among students but did not include empirical measurements of its impact on learning outcomes.

Hussein et al. (2022) examined in detail the use of gamified digital solutions in classroom mathematics instruction. An analysis of 59 publications indicates increased motivation to learn when using gamified platforms, but does not address students in higher education, particularly in the context of complex topics. Makoka (2023) provided empirical data on the impact of digital solutions on teaching in higher education, highlighting the shift in responsibilities between instructors and students in the context of digital interaction. However, the study did not assess outcomes across groups with different academic profiles and levels of preparation. Dokendorf and Gomez-Zakarelli (2024) examined the issue of pedagogical readiness for the digital transformation of mathematics education. The article summarizes approaches to digital integration in the training of future teachers, focusing on structural and content-related limitations. However, nothing was said about academic outcomes or changes in motivation. Similar limitations were identified in the work of Barchilon, Ben-Ava, and Gurevich (2023), who

investigated students' self-assessments regarding the digital environment. Thus, it was demonstrated that, although the general focus of the research was on describing digital tools and processes, a significant portion of the work was limited to theoretical or descriptive approaches without practical verification. No in-depth studies have been conducted to examine students' and instructors' perceptions of digital solutions in comparison with actual changes in motivation, satisfaction, and learning outcomes. Institutional differences in approaches to digital transformation and the educational consequences of the transition to an online format in the post-COVID period have not been fully explored.

The study aimed to identify statistically significant correlations between the intensity of digital educational platform use and the level of subject mastery, student motivation, and satisfaction with digital tools. The analysis addressed three research objectives: identifying differences in the perception of digital solutions by teachers and students; interpreting statistical relationships between the frequency of platform use and self-assessment of material mastery; and evaluating the impact of the digital component on the dynamics of learning motivation recorded before and after completing the training module.

2 METHODOLOGY

The theoretical and empirical study was conducted between January and April 2025 at two higher education institutions in the Kyrgyz Republic: Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov. These institutions were selected based on their current accredited curricula in the discipline of Mathematical Analysis (Jalal-Abad State University, named after B. Osmonov, 2023), as well as their active implementation of digital technologies in the educational environment. The theoretical part of the study was based on Order of the Ministry of Education and Science of the Kyrgyz Republic No. 1578/1 "On the Approval of State Educational Standards for Higher Professional Education" (2021), as well as on the approved work programmes for the discipline Mathematical Analysis, implemented both within the framework of the Mathematics programme and in an adapted form in educational modules on Informatics, posted on the official websites of the aforementioned universities. These documents provided for a four-semester course of 300 academic hours, including lectures, practical and independent work, which ensured a comprehensive analysis of the digital components in the content structure. The sample included 130 respondents, of whom 112 were undergraduate and master's students in mathematics and computer science, and 18 were teachers of relevant disciplines. Undergraduate and master's students were treated as one student group because they studied the same Mathematical Analysis module, used the same digital platforms, and completed the same pre- and post-module questionnaire. Separate comparison by academic level was not conducted, as the study focused on the general relationship between digital activity, motivation, satisfaction, and self-assessed mastery within the student sample. Teachers were included to verify the actual use of digital platforms in teaching practice, to clarify methodological integration of the tools, and to compare student perceptions with teacher assessments. The inclusion criteria were age 18 or older, participation in the current semester of the Mathematical Analysis course, and experience in using digital educational platforms. Individuals who were not involved in teaching or studying the course at the time of the study were excluded. The sample type was targeted and non-reproducible.

Within the educational and digital infrastructure, Moodle and Google Classroom platforms were used for course administration, GeoGebra, Desmos, and Microsoft Whiteboard for task visualisation and graphing, and Wolfram Mathematica and MATLAB for symbolic analysis and working with analytical equations. These platforms were chosen because they are widely used in international academic practice and are suitable for mathematical analysis tasks. The platforms were used in a blended learning format (a combination of face-to-face classes and online activities via digital environments).

The study consisted of three stages: initial, main, and final. At the initial stage, a questionnaire was conducted to identify basic digital competence and initial attitudes towards the introduction of computer technologies into the mathematical analysis course. During the main stage, the use of specific digital tools in real teaching practice was recorded. During this stage, participants studied a thematic module on mathematical analysis with the integration of digital platforms (GeoGebra, Desmos, Moodle, Wolfram Mathematica), which was used to analyse changes in students' learning motivation and satisfaction with digital tools during the final stage. The final stage involved a repeat survey and analysis of changes in the perception of the effectiveness of the digital component.

The questionnaire included 12 questions, 9 of which were closed-ended and 3 open-ended. In particular, respondents were asked to evaluate the frequency of use of the platforms, their convenience, and their impact on the mastery of key topics, including limits, series, derivatives, and integrals. Examples of questions included: "How often was GeoGebra used to plot functions?", "How much did using MATLAB help in solving differentiation problems?", "Which digital tools do you consider most effective in teaching mathematical analysis?". The survey was conducted separately for students and teachers, using an identical set of questions adapted in wording to the respective respondent status.

Data collection was conducted online using Google Forms, followed by statistical processing in IBM SPSS Statistics 28 software. The Mann-Whitney U test was used to analyse differences between subgroups, and Spearman's Rank Correlation Test (2025) was used to identify correlations between indicators. The level of statistical significance was set at $p<0.05$.

The study was conducted in accordance with the American Sociological Association Code of Ethics (1997), the ICC/ESOMAR International Code on Market and Social Research (2016), and the European Commission Guidelines (2021) on the protection of personal data. All participants provided written informed consent to participate in the study, to the processing of their personal data, and to the publication of anonymised results. Confidentiality was ensured by anonymising the questionnaires and excluding any data that could identify the participants. Only the research team had access to the data set.

3 RESULTS

3.1 Theoretical and regulatory guidelines for digital integration

The analysis of the digital component in the content of the course Mathematical Analysis was conducted based on the current educational standards of the Kyrgyz Republic and the approved work programmes

posted on the official websites of Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov (2023). A study of these sources confirmed that digital technologies occupy a stable and regulated place in the methodological support of the course, acting as its mandatory component, rather than a temporary or additional option. The documentation paid particular attention to the functional role of digital platforms in ensuring the visualisation, automation and control of the assimilation of key topics of analysis.

The programme structure at both universities was based on a four-semester model, including lectures, practical classes and independent study. However, there were differences in the level of formalisation of digital support: while in one programme digital tools were used only for certain topics, in the other they were present in the descriptions of most modules (Berdenova et al., 2019; Petrakov et al., 2019). In particular, the GeoGebra and Desmos platforms were used for topics related to graphical analysis, while Mathematica and MATLAB were used for differentiation and integration problems. Remote support systems, such as Moodle and Google Classroom, were provided as an integral part of the learning process, including uploading assignments, conducting tests, and monitoring activity. Table 1 below presents a comparison of the degree of integration of digital components into the work programmes of the two universities. Table 1 presents a comparison of the characteristics of the two universities' work programmes for the course Mathematical Analysis", including duration, number of hours and the presence of digital elements.

Table (1). Comparative analysis of the content and digital components of the syllabuses for the subject Mathematical Analysis at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov

Programme component	Kyrgyz State University named after I. Arabaev	Jalal-Abad State University is named after B. Osmonov
Total course volume (academic hours)	300	300
Duration of study	4 semesters	4 semesters
Form of presentation of digital technologies	In the explanatory note and thematic plan	In the explanatory note and methodological recommendations
Platforms for visualising functions	GeoGebra, Desmos	GeoGebra, Desmos
Platforms for calculation procedures	MATLAB, Wolfram Mathematica	Wolfram Mathematica, MATLAB
Digital systems	Moodle, Google Classroom	Google Classroom, Moodle
Mention of digital competences in the course objectives	Present	Mentioned indirectly
Sections with digital solutions integration	Limits, graphs of functions, derivatives, and integrals	Graphical analysis, numerical methods, verification tasks

Source: compiled based on an analysis of work programmes for the discipline "Mathematical Analysis" at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov (2023), based on data from official university websites, as well as Order of the Ministry of Education and Science of the Kyrgyz Republic No. 1578/1 "On the Approval of State Educational Standards for Higher Professional Education" (2021).

The data presented in Table 1 provided details on the implementation of the Mathematical Analysis course in terms of digital integration at two universities in the Kyrgyz Republic. In both cases, the curricula provided for a four-semester structure for mastering the discipline with a total volume of 300 academic

hours, which corresponds to the basic requirements of the State Educational Standard. However, the degree of formalisation of digital components varied.

At Jalal-Abad State University, named after B. Osmonov, digital technologies were mainly mentioned in explanatory notes, which indicated the advisability of using GeoGebra and Desmos to visualise limits, derivatives and integrals. At the same time, there were no specific methodological guidelines on the sequence or depth of their use, which suggests that digital support is optional (Martynyuk et al., 2023). In addition, the course structure did not stipulate the mandatory use of platforms for independent student work.

In contrast, at Kyrgyz State University named after I. Arabaev, digital elements were integrated in the form of clearly defined modules with the corresponding tools: MATLAB and Wolfram Mathematica were used in topics related to differentiation and numerical analysis, and GeoGebra was used when studying functions of several variables. Moodle and Google Classroom were used as mandatory electronic platforms, with fixed functions for monitoring, distributing materials and assessing assignments. The methodological recommendations for teachers emphasised the need to use digital resources at all stages of the course, including preparation for mid-term assessments (Gospodinova, 2023; Stamov et al., 2023). At Jalal-Abad State University, named after B. Osmonov, digitalisation was more of a recommendation and variable in nature, while at Kyrgyz State University, named after I. Arabaev, it was institutionalised and systematically integrated. The differences identified in the methodological development of digital solutions indicate not only different levels of technological maturity of educational processes, but also different approaches to ensuring students' digital mathematical literacy (Baizakov et al., 2019).

The observations confirmed that, despite the existence of a formally established regulatory framework, the possibilities for digital transformation in the educational process remain variable and depend on local administrative and methodological conditions and the professional position of the teaching staff. The distribution of digital platforms by type of educational activity, including testing, visualisation, analytical calculations, course administration, and communication, is described below.

Analysis of methodological materials identified a typology of digital tools recorded in the teaching materials for the discipline Mathematical Analysis. The study addressed both the functional features of each platform and the frequency of their mention in documents posted on internal university portals. The platforms GeoGebra (16 times) and Google Classroom (15 times) received the highest number of mentions. The former was actively used for graphing and visualising functions, due to its accessible interface and the ability to create interactive mathematical objects. The latter was used as a means of communication and distribution of teaching materials, as well as for organising ongoing feedback.

Moodle, mentioned 14 times, performed course management and test automation functions, reflecting the institutionalised use of the digital environment. Wolfram Mathematica (12 mentions) was used in the context of symbolic computation and analytical transformations, especially when studying derivatives, integrals, and limits. Desmos (10 mentions) was used for interactive graphical analysis,

mainly for visualising the behaviour of functions. The MATLAB software package, mentioned in nine methodological sources, was used primarily in the study of topics related to numerical methods and definite and indefinite integrals, which indicates its use for visual representation and solving applied problems within the framework of a mathematical analysis course. The least frequently mentioned platform was Microsoft Whiteboard (6 mentions), which served as a virtual whiteboard for explaining problems in a remote format.

Thus, the formalised digital component presented in the work programmes generally complies with the requirements of the state educational standards of the Kyrgyz Republic. At the same time, the nature of digital integration at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov differs in the degree of detail and methodological emphasis: while the former focuses on visualisation, the latter focuses on analytical and numerical-computational processing. This indicates the existing variability in the interpretation of digital approaches within a single regulatory framework.

3.2 Empirical recording of digital teaching and learning practices

Based on the summary of the results of a survey of teachers and students in the fields of mathematics and computer science at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov, an assessment of the actual use of digital platforms in the educational process was carried out. The data covered not only the frequency of use of specific tools, but also the context of their integration into teaching modules, thematic focus, forms of interaction, as well as subjective assessments of convenience and perceived effectiveness. The forms of digital integration ranged from demonstration fragments within lectures to full-fledged interactive modules, especially in topics requiring numerical calculations (Cherniha & Pliukhin, 2013; Kiurchev et al., 2024). Teachers pointed to the consistent use of digital resources, mainly when explaining complex analytical topics such as “Functions of several variables”, “Real numbers”, “Integrals with parameters”, and “Series”. The GeoGebra and Desmos platforms were used when visual support for the material was needed, while Wolfram Mathematica and MATLAB were used primarily for calculation tasks and laboratory assignments. Moodle and Google Classroom were used to organise ongoing assessment, upload materials, assign individual tasks and provide feedback.

Students, in turn, noted inconsistencies in practices between teachers and departments. Despite the availability of platforms, the level of engagement and digital support varied significantly (Al-Hawary et al., 2024). The most frequently mentioned forms of use were access to digital handouts, testing via LMS, and independent completion of tasks in visual environments. Table 2 shows the distribution of the frequency of use of specific platforms within individual course topics: limits, derivatives, integrals, and series.

Table (2). Frequency of use of digital platforms by course topic

Course topic	GeoGebra	Desmos	Wolfram Mathematica	MATLAB	Moodle	Google Classroom	Microsoft Whiteboard
Limits and continuity	85	60	20	15	95	90	30
Derivatives and function analysis	90	75	35	25	95	90	40
Integrals (definite and indefinite)	40	30	80	75	95	90	25
Real numbers	25	20	90	85	95	90	15
Rows and sequences	35	50	25	20	95	90	20
Functions of several variables	70	45	40	35	95	90	35

Source: compiled based on the generalisation of data from methodological materials and digital platforms used in teaching mathematical analysis at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov (2023), based on resources from GeoGebra, Desmos Inc., Wolfram Research, The MathWorks, Inc., Microsoft, Google, as well as the core undergraduate curriculum.

The results presented in Table 2 reflect the pronounced functional differentiation of digital platforms depending on the thematic blocks of the Mathematical Analysis course. The frequency of use was calculated based on a generalised content analysis of teacher questionnaires (n=18), work programmes, and methodological materials, which recorded mentions of specific platforms for each topic. GeoGebra and Desmos were used in topics that required the visualisation of mathematical concepts: "Derivatives and Function Analysis" (GeoGebra – 90 mentions, Desmos – 75), "Limits and Continuity" (GeoGebra – 85, Desmos – 60). In the topics "Integrals" and "Real Numbers", Wolfram Mathematica (80 and 90 mentions, respectively) and MATLAB (75 and 85 mentions) were used most often, which corresponded to their functionality in the field of numerical and symbolic calculations. Microsoft Whiteboard was used as an interactive tool for synchronous support in online classes; the average number of mentions across all topics was 27. Moodle and Google Classroom showed stable frequency across each of the six blocks (90-95 mentions each), reflecting their widespread institutional implementation for course administration. Thus, each tool performed specific tasks corresponding to the content and form of presentation of the teaching material.

The Moodle and Google Classroom platforms were used consistently across all topics, with a range of mentions from 90 to 95. The use of these platforms did not correlate with the content of individual topics, as their functionality covered general electronic course support: administration, placement of teaching materials, testing, and feedback. Thus, these platforms served as a mandatory digital infrastructure component of the educational process. Based on the compared data, a stable relationship was established between the type of learning task and the choice of digital tool. Visualisation platforms dominated in theoretical sections, symbolic calculation tools in applied sections, and universal environments functioned as a permanent channel for organising educational communication (Amourah et al., 2025). All this highlights a conscious and functionally conditioned digital integration into the teaching of mathematical analysis at universities in the Kyrgyz Republic. Figure 2 shows the levels of digital engagement of students and teachers based on the generalised results of the survey.

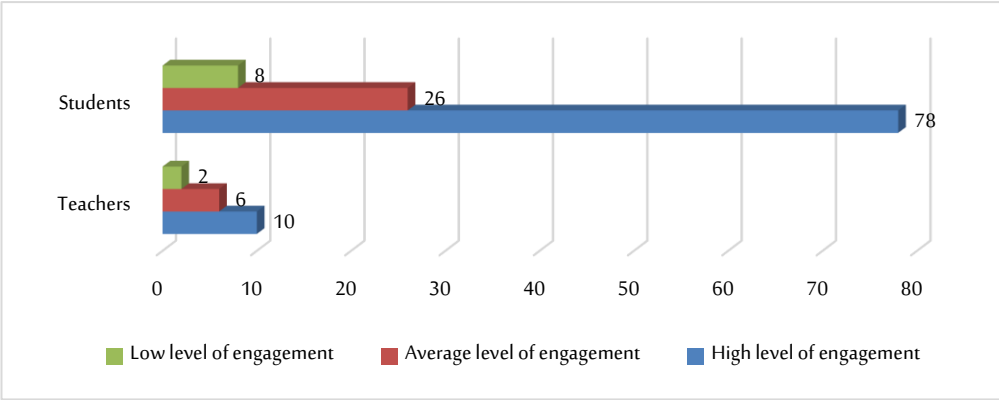


Figure (2). Level of Digital Engagement among Teachers and Students

Source: compiled based on the analysis of empirical data collected at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov, drawing on methodological approaches to digital pedagogy presented in the works of Dockendorff and Gomez Zaccarelli (2024), Güngördü and Yıldırım (2025), Matthews and Zimmer (2022), as well as platform solutions from Google, Microsoft, and Moodle.

The data in Figure 2 showed a similar but not identical degree of digital engagement between the two groups. Among the 18 teachers surveyed, 10 demonstrated a high level of engagement, which corresponded to 55.6%. Six teachers (33.3%) positioned themselves at an average level, and two participants reported low activity (11.1%). Thus, more than half of the teachers systematically used digital tools, while a third limited themselves to occasional use, mainly for administrative purposes. In the student sample of 112 people, 78 respondents, or 69.6%, reported a high level of engagement. The average level was reported by 26 students (23.2%), and the low level by 8 (7.1%).

The level of engagement was assessed based on participants' self-descriptions in questionnaires, which included a scale of frequency of digital platform use (from “daily” to “less than once a month”), types of activity (educational, administrative, communicative) and a subjective assessment of the role of digital tools in the learning process. These parameters were used for a preliminary gradation into high, medium, and low levels of digital activity. This implies that digital resources were not only accessible but also perceived by students as an integral part of the educational environment: most students regularly used platforms for visualisation and calculations, as well as for interacting with teachers (Asanov & Orozmamatova, 2019).

The comparison showed that the proportion of students actively involved in digital activities was higher than that of teachers. However, the difference was moderate, which indicates a general increase in digital culture in the academic environment and shows that teachers, despite age and professional differences, have generally adapted to the requirements of digital learning. Table 3 shows the final ratings for the usability of the platforms based on three criteria: navigation, accessibility, and functionality.

Table (3). Perception of the convenience of digital platforms (based on the results of the final survey)

Digital platform	Average comfort rating (1-5)	Standard deviation
GeoGebra	4.6	0.4
Desmos	4.4	0.5
Wolfram Mathematica	3.9	0.6
MATLAB	3.8	0.7
Moodle	4.2	0.5
Google Classroom	4.3	0.4
Microsoft Whiteboard	3.6	0.6

Source: compiled based on the analysis of the results of the final survey of 3rd and 4th year students majoring in Mathematics and Computer Science at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov, based on the methodology for evaluating the user experience of digital platforms presented in the works of Cirneanu and Moldoveanu (2024), Viberg et al. (2020), as well as on the interface characteristics of the GeoGebra, Desmos, Wolfram Research, The MathWorks, Inc., Moodle and Google platforms themselves.

The results of the latest survey, presented in Table 3, reveal discrepancies in participants' assessments of the usability of digital platforms. The GeoGebra platform received the highest average score (4.6). The low standard deviation (0.4) indicates a high level of agreement among respondents. This indicates the platform's successful integration into the learning process and its usefulness for visualizing functions and graphical representations. The high rating is likely due to its simple interface and the fact that teachers and students can use it without any technical knowledge. Second place went to the Desmos platform with an average rating of 4.4 and slightly greater variation in ratings (σ=0.5). This can be explained by the fact that Desmos was not used in all course modules, but primarily in topics related to graphical analysis. Some respondents viewed the platform as a supplementary tool, while for others it was an indispensable learning tool.

Platforms such as Moodle (4.2) and Google Classroom (4.3) also received high ratings, indicating their important role in organizing the learning process. These digital tools were used to conduct the course, post learning materials, track assignment completion, and administer tests. A low standard deviation (0.4–0.5) indicated that respondents had a stable and consistent perception of these platforms, regardless of their level of digital proficiency. Widespread adoption at the institutional level and technological support at universities contributed to an improved user experience. More technical platforms, such as Wolfram Mathematica (3.9) and MATLAB (3.8), received moderate usability ratings. At the same time, higher standard deviation values were recorded (0.6 and 0.7, respectively), indicating the difficulties some respondents faced when working with these tools. The main problems mentioned were the need to learn a specific syntactic structure, lack of general access, and limited applicability within the course. This suggests that these platforms were used primarily by instructors, while students did not fully understand them.

Microsoft Whiteboard was recognised as the least convenient platform, with a rating of 3.6 and a standard deviation of 0.6. Analysis of open comments showed that the main problem was limited functionality when working together, especially in a remote format. The use of the Whiteboard was sporadic and, as a rule, did not go beyond demonstrating solutions to problems in real time. Platforms

that were actively integrated into teaching and had an intuitive interface received high ratings. Conversely, highly specialised tools or secondary services used sporadically were perceived as less convenient. These differences highlight the need for targeted digital training for participants in the educational process and the thoughtful methodological integration of digital tools into the course structure.

3.3 Statistical interpretation and pedagogical significance of the results

To identify significant differences in the perception of digital platforms between groups of respondents, as well as to determine the relationship between frequency of use, satisfaction, and level of material assimilation, statistical processing of the final questionnaire data was carried out. For intergroup comparison (teachers and students), the Mann-Whitney U test was used, which established statistically significant differences in the assessment of platforms such as GeoGebra and Wolfram Mathematica ($p<0.05$). For the other platforms, no statistically significant differences were observed between the groups of teachers and students ($p>0.1$), which indicates a similarity in user experience at a basic level of digital competence. Teachers demonstrated a higher subjective assessment of the functionality of analytical systems, while students rated the accessibility of visual and administrative tools higher. Correlation analysis performed using Spearman's rank correlation coefficient revealed a positive relationship between the frequency of platform use and the level of satisfaction of respondents ($\rho=0.62$ for GeoGebra; $\rho=0.58$ for Moodle).

A statistically significant correlation has been established between the regularity of digital platform use and the level of their perception, indicating the formation of sustainable user strategies and an increase in subjective satisfaction with digital tools. The highest satisfaction values were observed in topics where digital platforms were used as the primary means of explanation and visualisation (in particular, when studying limits, derivatives, and graphical models of functions). In addition, a statistically significant relationship was found between the level of digital engagement and self-assessment of success in mastering the mathematical analysis course ($\rho=0.54$, $p<0.01$). Respondents with high digital activity more often reported full or partial mastery of all course modules and demonstrated better results on the final module test: the average increase in points compared to the initial control work was 14.2% (from 67.1 to 81.3 points out of a possible 100). Table 4 shows the Spearman correlation coefficients between the intensity of platform use and the level of mastery of course topics (as self-assessed by students).

Table (4). Spearman correlation coefficients for digital activity, satisfaction, and self-assessed learning outcomes

Indicator pair	Spearman's ρ	Interpretation
Frequency of GeoGebra use and satisfaction with the platform	0.62	Moderate positive correlation
Frequency of Moodle use and satisfaction with the platform	0.58	Moderate positive correlation
Overall digital engagement and self-assessment of subject mastery	0.54	Moderate positive correlation
Regularity of digital tool use and self-assessment of learning outcomes	0.47	Moderate positive correlation

Source: compiled based on an analysis of questionnaire and rating data from students at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov, using Mann-Whitney's U-test and Spearman's Rank Correlation Test (2025), as well as based on methodological provisions from Dockendorff and Gomez Zaccarelli (2024), Hussein et al. (2022), and Matthews and Zimmer (2022).

The data presented in Table 4 show that regular use of digital platforms was positively associated with satisfaction and self-assessed mastery of mathematical analysis. The strongest relationship was recorded for GeoGebra use and satisfaction with the platform (ρ=0.62), followed by Moodle use and satisfaction (ρ=0.58). Overall digital engagement was also positively related to self-assessment of subject mastery (ρ=0.54), while regularity of digital tool use correlated with self-assessment of learning outcomes (ρ=0.47).

These results indicate that the pedagogical effect of digital platforms depended not only on their technical characteristics, but also on the regularity and methodological consistency of their use. Figure 3 shows a comparison of satisfaction with digital tools between teachers and students.

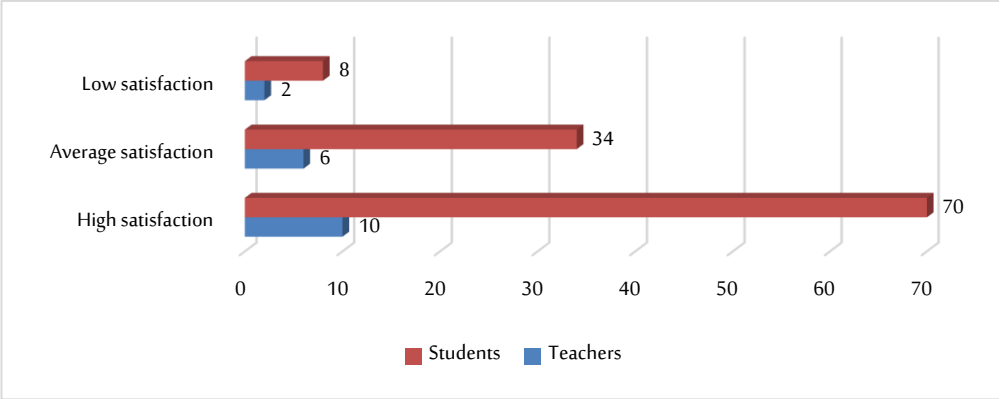


Figure (3). Comparative Analysis of Satisfaction with Digital Solutions by Group

Source: compiled based on the analysis of empirical data from the final survey of students at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov, using digital engagement assessment criteria (Matthews & Zimmer, 2022; Mahmud et al., 2022) and statistical approaches outlined in Spearman's Rank Correlation Test (2025), Dockendorff and Gomez Zaccarelli (2024), as well as considering platform characteristics based on data from Google, Microsoft, and GeoGebra.

The results presented in Figure 3 show a noticeable, though not radical, difference in the level of satisfaction with digital solutions between the two target groups of teachers and students. In the group of teachers, 55.6% (10 out of 18 respondents) rated their experience of using digital platforms as "highly satisfied", indicating a predominantly positive attitude towards digital tools among more than half of those surveyed. At the same time, the proportion of students who expressed a high degree of satisfaction was 62.5% (70 out of 112). This can be explained by the higher degree of adaptation of students to the digital environment, formed through the regular use of electronic services in educational and everyday practices, as well as the prevalence of hybrid and online formats in the process of academic socialisation. An average level of satisfaction was observed among 33.3% of teachers (6 out of 18) and 30.4% of students (34 out of 112), which confirms the presence of moderately positive attitudes in both groups. A low level of satisfaction was significantly less common, with only 2 teachers (11.1%) and 8 students (7.1%) reporting it. These data may indicate either technical difficulties or insufficient adaptation of individual participants to digital forms of interaction. The data in Figure 4 reflect the self-assessment of students' motivation before and after completing the digital module, according to the final questionnaire.

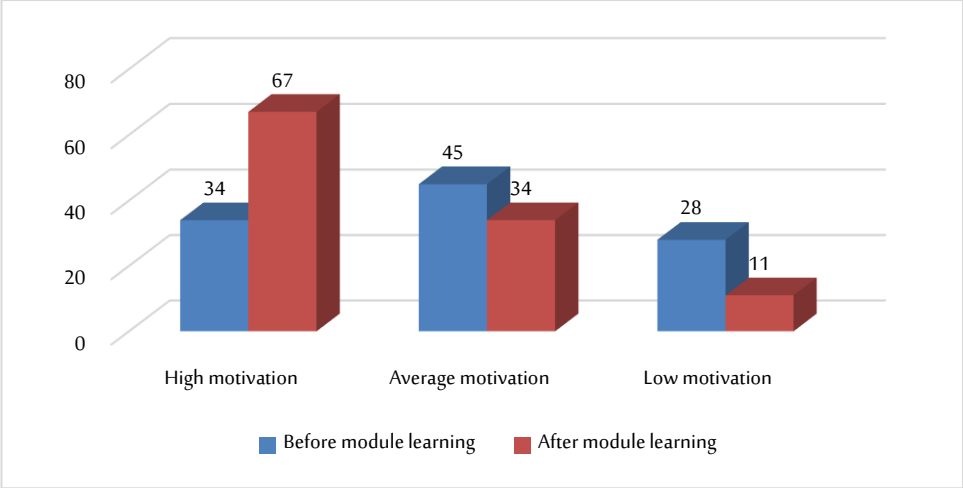


Figure (4). Dynamics of Students' Learning Motivation before and after the Digital Module

Source: compiled based on an analysis of the results of a survey conducted by Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov, with reference to the conceptual provisions of studies by Maniraho et al. (2023), Shi (2022), Krajnc (2021), as well as methodological guidelines proposed by Herbst et al. (2024), and data from the GeoGebra, Desmos, and Moodle platforms.

The data presented in Figure 4 demonstrated quantitative and qualitative positive dynamics in the change in students' academic motivation after completing the digital module on mathematical analysis. Before the module began, 34 students reported high motivation, accounting for 30.4% of the entire student sample (out of 112 respondents), while after its completion, the number of students with high motivation increased to 67, or 59.8%. Thus, an increase of 33 students was recorded, reflecting the positive impact of the digital environment on learning activity. The category of average motivation decreased from 45 to 34 students, i.e. by 11 people (from 40.2% to 30.4%), which may indicate a partial redistribution towards increased motivation. Particularly noteworthy is the decrease in the low motivation group: from 28 students to 11, i.e. from 25% to 9.8%. This decrease of 17 students (15.2% in percentage terms) confirms that digital tools not only activated strong students, but also contributed to the inclusion of previously unmotivated students in the active mastery of the material. The numerical shift towards a higher motivation profile covered 50 respondents (33 moved to high motivation, 17 from low to medium or high), which is 44.6% of the entire student sample, interpreting digital transformation not as a technical addition, but as a factor of sustainable pedagogical impact.

Concluding the analysis, it is possible to state that digital integration into the teaching of mathematical analysis is based on the normatively established presence of digital platforms in educational courses and methodological materials. Empirical data confirmed the active use of digital solutions by teachers and students, considering differences in thematic blocks and university profiles. Statistical interpretation revealed stable links between the level of digital activity, academic motivation, satisfaction, and perception of the effectiveness of content mastery, which indicates the potential of digital tools in the structural transformation of the educational process.

4 DISCUSSION

A study conducted in 2024-2025 by the departments of mathematics and mathematics education at Arabaev Kyrgyz State University (Bishkek) and Jalal-Abad State University (Jalal-Abad) revealed the quantitative and qualitative parameters of the influence of the digital platforms GeoGebra, Desmos, Moodle, and Wolfram Mathematica on learning motivation and mastery of topics in a mathematical analysis course. The results obtained during the study confirmed the existence of a stable relationship between the intensity of digital platform use and the level of mastery of course topics. This relationship was particularly evident in the analysis of data on the GeoGebra and Desmos platforms, where respondents with high digital activity demonstrated better results in final testing and self-assessment of success. A comparison with the results presented in the study by Widihastuti et al. (2024) revealed a coincidence in the assessment of the impact of digital tools on learning productivity. In both cases, an increase in the effectiveness of material assimilation was recorded with the systematic use of digital solutions.

The discrepancy between teachers' and students' assessments is consistent with the findings of Pazuch and Gumiero (2024) regarding the impact of teachers' digital learning on improving the quality of mathematics instruction. The study showed that teachers with more professional experience preferred platforms with analytical functions, while students more often rated visual and adaptive interfaces positively. These discrepancies corresponded to observations regarding the impact of digital skills on tool selection. De Mello and de Azevedo Basso (2024) confirmed that the success of digital integration depends not only on available resources but also on the degree of their methodological relevance. An analysis of the digital environment at two universities with different academic profiles led to similar conclusions. Higher levels of satisfaction and motivation were recorded where platforms were systematically integrated into the modular course structure and accompanied by advisory support (Kerimkhulle & Aitkozha, 2017; Kerimkhulle et al., 2022).

According to Mahmud et al. (2022), there is a need to incorporate digital literacy into the design of distance learning courses. The study sample revealed the following aspects: students who had prior experience with digital tools adapted more easily to new formats and demonstrated higher learning outcomes, while those with the least digital experience reported greater difficulties. Shi (2022) conducted an experimental study on the inclusion of gamification elements in the teaching of mathematical concepts. The study showed that interactive digital components are effective for maintaining attention and increasing cognitive engagement. Although the study did not specifically examine game-based activities, the noted increase in motivation to learn after completing the digital module highlighted the value of a dynamic interface and interactive visuals.

The digital teaching analysis model proposed by Clark Wilson and Simsek (2024) emphasised the need to structure the educational process when using technology. The data obtained confirmed that platforms integrated into the architecture of training sessions (e.g., through regular testing and visual simulations) were rated as more useful and convenient. In contrast, platforms with fragmented use showed lower

ratings and a weak correlation with mastery indicators. Koyunkaya and Bozkurt (2022) examined the impact of practice-oriented assignments on students' readiness to use digital resources. The study determined that it was the repeated use of platforms with functional feedback that formed a stable habit and positive attitude towards the digital environment. Similar dependencies were also recorded in the questionnaire: the intensity of use directly correlated with the subjective assessment of the convenience and usefulness of the tools.

Tamborg et al. (2024) raised the issue of the need to clarify the concepts of digital competence for mathematics teachers. A comparison of indicators at Kyrgyz State University named after I. Arabaev and Jalal-Abad State University named after B. Osmonov showed that the level of technological infrastructure and the type of academic specialisation had an impact on the nature of digital engagement. At Jalal-Abad State University named after B. Osmonov, there was a higher level of interest in analytical platforms, while at Kyrgyz State University named after I. Arabaev, visualisation and communication tools were more commonly used. Herbst et al. (2024) emphasised the importance of asynchronous digital simulations in the professional development of mathematics teachers. Their findings coincided with the observation made in this study that teachers who actively interacted with digital environments demonstrated a more structured perception of platforms and evaluated them not as an auxiliary but as a systemic component of the educational process.

A study by Pessoa da Silva et al. (2023) emphasised that the effectiveness of digital technologies depends on the degree of their didactic adaptation and contextual relevance. The data obtained demonstrated that in study groups where digital tools were integrated into specific topics and course assignments, higher satisfaction and a significant increase in motivation were recorded, which corresponds to the observations of the authors mentioned above. Matthews and Zimmer (2022) presented a model of digital mentoring, in which the professional development of teachers was accompanied by the formation of sustainable digital competencies. A similar pattern was observed in the Kyrgyz universities studied: teachers who had undergone preliminary training in digital pedagogy not only used the platforms more actively but also demonstrated more flexible strategies for supporting students in the digital environment.

Krajnc (2021) maintained that achieving a high level of mathematical literacy is possible provided that digital tools are used critically and innovatively. Participants who demonstrated high levels of satisfaction and motivation most often used not just the standard functions of the platforms, but also active elements of interaction, dynamic models, tasks with automatic feedback, and simulations. These observations correlated with the previously mentioned fact that the depth of mastery of digital solutions has a direct impact on academic success. Dai et al. (2024), within the framework of the extended UTAUT 2 model, identified factors influencing teachers' willingness to use digital resources when teaching mathematical cultures. Similar barriers and motivational attitudes were observed in the sample: teachers who were not involved in digital training were less likely to use resources on their own initiative and more likely to view digital platforms as an additional burden, reflecting the need for institutional support for digitalization (Cherniha et al., 2008; 2016).

Rodrigues (2020) proposed a model of active digital training for future teachers, where the use of digital tools in the process of developing real lessons took centre stage. In the context of Kyrgyz State University named after I. Arabaev, this strategy proved to be particularly effective: students involved in the digital design of modules demonstrated higher motivation and a further analysis of digital practices, which was confirmed by the results of questionnaires and self-assessments. Akhayeva et al. (2024) considered the introduction of artificial intelligence technologies into the teaching of higher mathematics as a means of improving the professional prospects of future IT specialists. Although the study did not focus on artificial intelligence, the general vector for technological renewal in mathematics education coincided with the trends recorded in other works: participants from Jalal-Abad State University named after B. Osmonov demonstrated increased interest in digital tools with advanced functionality, such as Wolfram Mathematica and MATLAB. A study by Maniraho et al. (2023) found that including teachers in digital learning teams contributed to a more positive perception of digital technologies in educational practice. Similarly, teachers who were involved in modifying and adapting digital modules within the course demonstrated more positive assessments of the digital environment and actively offered recommendations for its improvement.

Thus, a comparison of the results obtained with international studies confirmed that the impact of digital platforms on student motivation and learning outcomes at universities in Kyrgyzstan is consistent with global educational trends. The identified differences in the perception of the digital environment between teachers and students, as well as the recorded correlations between the frequency of platform use and the level of subject mastery, testify to the systemic nature of digital integration. This made it possible to consider digital tools not as an auxiliary means, but as a full-fledged component of the modern pedagogical model.

5 CONCLUSION

The study confirmed that the regular use of digital platforms in teaching mathematical analysis was positively associated with students' motivation, satisfaction, and self-assessed mastery of course content. After completing the digital module, the proportion of students with high motivation increased from 30.4% to 59.8%, while the proportion of students with low motivation decreased from 25% to 9.8%. These results show that digital tools contributed not only to the activation of already motivated students, but also to the involvement of students who initially demonstrated lower motivation.

Statistical analysis showed positive correlations between digital activity and learning-related indicators. Regularity of digital tool use correlated with self-assessment of learning outcomes (ρ=0.47), while overall digital engagement correlated with self-assessed mastery of mathematical analysis topics (ρ=0.54, $p<0.01$). The frequency of using GeoGebra and Moodle was also positively related to satisfaction with these platforms (ρ=0.62 and ρ=0.58, respectively). These findings confirm that the effectiveness of digital integration depends on systematic and methodologically organised use rather than on the mere availability of platforms.

The results also showed differences in the functional role of platforms. GeoGebra and Desmos were most effective for visualising functions, limits, and derivatives, while Wolfram Mathematica and MATLAB were more relevant for analytical and numerical calculations. Moodle and Google Classroom performed a stable administrative and communication function. Institutional differences were identified: at Kyrgyz State University named after I. Arabaev, the emphasis was on visualisation and methodological structure, while at Jalal-Abad State University named after B. Osmonov, the emphasis was on calculation accuracy and algorithmisation.

The study was limited by the small sample size of two universities and the lack of external pedagogical verification of the data obtained. Further research could expand the geographical scope of the sample and apply longitudinal mixed methods to comprehensively assess the impact of digital integration.

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