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FACTORS ASSOCIATED WITH DIGITAL TECHNOLOGY INTEGRATION IN MATHEMATICS EDUCATION IN THE CONTEXT OF CALCULUS TEACHING

Abstract

Digital technologies have become increasingly common in mathematics education, but their use in calculus varies across educational settings. This study examines the factors associated with digital technology integration in mathematics education using calculus teaching as the specific context of the study. The study involved 176 participants, including 36 mathematics educators and 140 learners, and the survey data were analyzed using descriptive statistics, principal component analysis (PCA), and analysis of variance (ANOVA). The PCA identified five exploratory components explaining 35.52% of the total variance, with statistically significant differences found for three of them. These components reflected professional and institutional characteristics, perceptions of mathematical content and instructional decisions, and professional development and methodological support. Generally, it was found that digital tools were positively perceived in terms of representing mathematical concepts and simplifying abstract ideas. At the same time, their reported use varied across educational contexts, suggesting that access to technology alone does not determine how it is incorporated into calculus teaching and learning. The results point to the importance of educational and professional factors when considering the role of digital technologies in mathematics education.

Keywords: calculus education, digital technology integration, mathematics education, digital competence, professional development, digital tools, differential and integral calculus, student engagement.

Introduction. The growing use of digital technologies has changed the way mathematical ideas can be presented and explored in the classroom. Graphing applications, Computer Algebra Systems, and interactive environments make it possible to work with mathematical concepts through symbolic, numerical, and graphical representations rather than relying on calculations alone. This is particularly useful in differential and integral calculus, where understanding often requires students to connect different representations of limits, derivatives, and integrals. Making these connections can be difficult, especially during the transition from school mathematics to the more formal reasoning expected at university level [1, 2].

Digital tools can support this process by allowing learners to visualize changes, experiment with mathematical relationships, and examine the same problem from different perspectives. At the same time, the presence of technology in an educational setting does not guarantee that it will become part of everyday mathematics teaching. The way digital resources are used may depend on many factors, including experience with technology, confidence in using it for mathematical tasks, and the conditions available within a particular educational environment.

The relevance of this study is linked to a practical issue: the growing availability of digital technologies does not necessarily translate into their regular and meaningful use in mathematics education. This gap becomes especially important in calculus, where digital tools can provide additional ways of working with concepts that are difficult to represent using traditional approaches alone. The availability of technology is just one aspect of the issue, however. Factors such as education and experience, digital skills and environments play an important role in technology adoption.

The situation is especially significant in Kazakhstan, as digitalization is one of the main directions of the educational development. While the access to technology has increased among many educational institutions, conditions for their application differ greatly. The differences in infrastructure, digital competence, education, and experience may be associated with differences in the extent to which technology is used for teaching purposes.

The aim of this study is to describe perceptions of digital technology use in calculus education and to explore patterns in mathematics educators' responses concerning technology integration. The study considers educators' and learners' perceptions and reported use of digital technologies, examines the component structure of educator responses, and explores differences in component scores across empirically derived educator profiles. Given the cross-sectional design and exploratory nature of the analysis, the results are interpreted in terms of associations and group differences rather than causal effects.

Literature Review. The use of technology in mathematics education is closely connected with the idea that mathematical understanding develops through active engagement rather than through the passive reception of information. From a constructivist perspective, learners build new knowledge by relating unfamiliar ideas to what they already know and by testing these connections through exploration and reflection. Digital environments can support this process in ways that are difficult to reproduce with static materials. Computer Algebra Systems, interactive graphs, and simulations allow learners to change parameters, observe the results, and move between different representations of the same mathematical idea [3, 4].

The educational value of such tools, however, cannot be separated from users' ability to work with them. Digital literacy has therefore become increasingly relevant to mathematics education. Evidence from Kazakhstan suggests that the development of students' digital skills is shaped not only by what is available at school. Joshkun et al. (2024), using data collected between 2016 and 2022, found that access to the Internet at home had a stronger relationship with schoolchildren's digital skills than access to technology at school [5]. This points to an important distinction between access and actual competence: providing digital resources is necessary, but it does not ensure that learners will be equally prepared to use them for educational purposes.

This distinction is especially important in calculus. Learning calculus involves working with concepts that can be expressed symbolically, numerically, and graphically, and understanding the connections between these forms is often difficult for students. Research in calculus education has repeatedly documented problems with limits, derivatives, and integrals, particularly when students are expected to move beyond procedural differential and integral calculation and explain the underlying mathematical relationships [2, p.4]. These difficulties can become more pronounced during the transition to university, where formal definitions, abstract reasoning, and mathematical proof take a more prominent role [6].

Several theoretical approaches help explain why these difficulties persist. Vinner's (2002) distinction between concept image and concept definition shows how a learner's intuitive understanding of a mathematical idea may differ from its formal definition [7]. Tall and Vinner (1981) further showed that learners' concept images may not fully correspond to formal mathematical definitions [8]. Although these approaches describe mathematical understanding from different perspectives, they point to a common problem in calculus learning: successful performance with procedures does not necessarily mean that the underlying concepts are well understood.

Digital technologies are particularly relevant in this context because they allow students to approach the same calculus concept in more than one form. Graphing environments can show how a function changes as its parameters vary, while Computer Algebra Systems can support experimentation with symbolic expressions and calculations. Dynamic representations can also make relationships between symbolic and graphical forms more visible [4, p.93]. The contribution of technology is therefore not limited to making calculations faster. Its educational value lies partly in creating opportunities to explore mathematical relationships that are difficult to see when concepts are presented only through formulas and static diagrams.

Evidence accumulated over several decades generally supports the use of technology in mathematics education, although the size and nature of its effects vary. Young (2017), in a second-order meta-analysis covering approximately 30 years of research, reported a moderate positive effect of technology-enhanced instruction on mathematical achievement [9]. Technologies that supported computation and interactive exploration were among the approaches associated with positive outcomes. At the same time, the review raised questions about whether short-term gains in performance necessarily translate into lasting improvements in mathematical reasoning and conceptual understanding. This distinction is important because the educational value of technology depends on what students actually do with it rather than simply on whether a digital tool is present.

For this reason, research has increasingly shifted from asking whether technology is useful to examining how it is incorporated into teaching. Drijvers (2015) argues that the effectiveness of digital tools depends on the relationship between the technology itself, the mathematical task, and the way instruction is organized. A tool with strong technical capabilities may contribute little if it is poorly connected to the learning objective or used only as an additional means of performing routine calculations [10]. The competence and experience of educators are therefore important parts of the integration process.

Digital technologies have also expanded beyond instruction into other areas of mathematics education. Computer Adaptive Testing, for example, allows assessment tasks to be adjusted to individual performance and provides a different approach to differentiated assessment. Internet-based technologies have likewise been used to support criteria-based assessment and more timely feedback [11]. These developments illustrate that digitalization can affect not only how mathematical content is presented but also how learning is monitored and supported.

The question of integration is particularly relevant in Kazakhstan, where schools and educational institutions have experienced substantial digital development. Yet greater availability of digital resources does not imply that they are used in the same way across contexts. Joshkun et al. (2024) demonstrate the importance of conditions outside school for the development of digital competence, while recent research on calculus education in Kazakhstan has identified differences associated with educational and professional characteristics [5, p. 2]. Sabyrkhanova et al. (2026), for example, reported variation in the difficulties identified in calculus learning according to teachers' experience and qualification level [1, p. 39]. Other studies have similarly emphasized the importance of professional preparation and institutional conditions for the effective use of technology in education.

Taken together, previous studies provide substantial evidence for the educational possibilities of digital technologies, including their use in mathematics and calculus. What remains less clear is why these possibilities translate into regular practice in some educational settings but not in others. Studies often concentrate either on the learning effects of a particular digital tool or on general attitudes toward technology, while the factors associated with different patterns of technology integration receive less attention.

Although prior research has documented the potential of digital tools for visualization, multiple representations, and mathematical exploration, three limitations remain. First, much of the literature evaluates particular tools or learning outcomes rather than examining professional, instructional, and institutional characteristics together. Second, evidence specifically concerning calculus education in Kazakhstan remains limited. Third, studies rarely compare educators' and learners' perceptions while also exploring heterogeneity within the educator group. The present study addresses this descriptive and contextual gap; it does not claim to validate a general measurement model or establish causal determinants of technology adoption.

Accordingly, the study addresses the following research questions:

RQ1. What patterns characterize educators' and learners' perceptions of digital technology use in calculus education?

RQ2. What underlying dimensions can be identified in educators' responses concerning digital technology integration in calculus education?

RQ3. How do the identified dimensions vary across empirically derived educator profiles?

The study's scientific novelty is contextual and exploratory. It provides evidence from Kazakhstan that combines educator–learner descriptive comparisons with an exploratory analysis of educator response patterns in calculus education. Its contribution is the identification of candidate professional, instructional, and support-related dimensions for subsequent validation in a larger educator sample. The retained components are therefore treated as provisional empirical patterns rather than established latent constructs.

Methods and Materials. The data for this study were collected as part of a broader dissertation study entitled “Innovative Forms and Methods for Preparing Future Mathematics Teachers to Teach Differential and Integral Calculus.” The survey developed for the research covered two main areas. The first examined difficulties encountered in the teaching and learning of calculus and was analyzed in an earlier publication [1, p. 38]. The second focused specifically on digital technologies, including their use in calculus education, difficulties associated with their integration, and the support needed for their effective use. The present article focuses exclusively on the second area of the survey, which was not examined in the previous publication, and analyzes patterns of digital technology integration in calculus education.

The survey included 176 respondents: 36 mathematics educators and 140 learners studying calculus or introductory calculus. Separate questionnaires were used for educators and learners. The educator questionnaire consisted of 20 numbered items and covered educational and professional characteristics, perceptions of the content and difficulties of teaching calculus, the use of digital technologies, perceived benefits and challenges of technology integration, previous technology-related training, and professional development and support needs. The learner questionnaire addressed corresponding aspects from the learners' perspective, including difficulties in learning calculus, the use of digital technologies in mathematics lessons, and their perceived influence on engagement and motivation. The questionnaires included closed, multiple-response, and open-ended items, with several closed questions using three response categories (“agree,” “partially agree,” and “disagree”). The questionnaires were developed by the authors in Kazakh and Russian and were presented bilingually within the same Google Form, allowing respondents to read each item in either language. Participation in the survey was voluntary. The questionnaires were completed anonymously through Google Forms, and the collected data were analyzed and reported only in aggregated form. The present study focuses on the items related to digital technology integration, while the results concerning difficulties in teaching and learning calculus were analyzed in the previous publication. The educational and professional characteristics of the mathematics educators are presented in Table 1.

Table 1. Educational and professional characteristics of the mathematics educators

Education, %		Years of Experience, %		Qualification Category, %		Language of Instruction, %	
Bachelor	36	Less than 1 year	11.5	Pedagogue	33	Kazakh	78
Master	64	1–5 years	33	Pedagogue-Moderator	20	Russian	22
		5–10 years	8	Pedagogue-Expert	25		
		10–15 years	22	Pedagogue-Researcher	22		
		15–20 years	14				
		More than 20	11.5				

Source: compiled by the authors.

Data processing and statistical analysis were carried out in Jupyter Notebook. Survey responses were coded numerically, and categorical variables were converted into dummy variables where required. Descriptive statistics were used to summarize the responses. The distributions of the variables were examined before further analysis. Variables included in the multivariate analysis were standardized to place them on a comparable scale. Descriptive comparisons of perceptions of digital technology use included both educators and learners. The subsequent multivariate analysis of

professional and educational characteristics was conducted for the educator subsample ($n = 36$), because variables such as teaching experience, educational background, and qualification category were applicable only to educators.

Principal component analysis (PCA) was used as an exploratory dimension-reduction technique for the educator subsample ($n = 36$). PCA was performed on standardized variables, and component scores were retained for subsequent exploratory analysis. The retained components were interpreted from the variables with the strongest loadings. Three educator profiles were then derived empirically from the PCA component-score space. One-way analysis of variance (ANOVA) was used to describe differences in PC1–PC5 scores across these three profiles. Because the profiles were created from the same component scores that were subsequently compared by ANOVA, these tests are circular and descriptive rather than independent confirmatory tests. Accordingly, they are not interpreted as independent evidence of differences associated with specific professional or educational characteristics.

Results and Discussion. The descriptive comparison indicated different reported experiences of digital technology use. Approximately 50% of educators selected occasional use, compared with slightly more than 20% of learners. These percentages describe responses to corresponding items in two separate questionnaires; the groups were not pooled in PCA or ANOVA, and no inferential test of the educator–learner difference was conducted. Approximately 47% of educators and 45% of learners reported perceived improvement in learning outcomes (fig. 1). The similarity is descriptive and should not be interpreted as statistical equivalence.

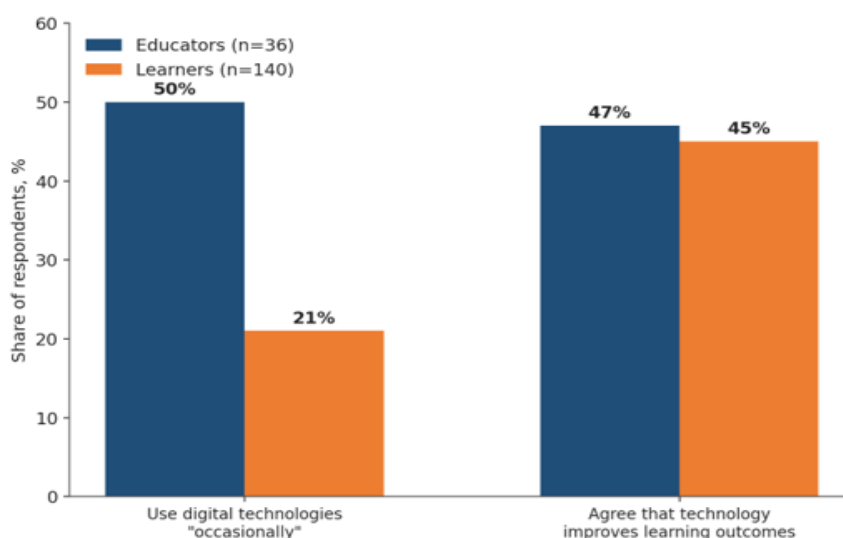


Figure 1. Comparison of educators' and learners' perceptions

Source: compiled by the authors.

The educator responses also revealed a difference between positive perceptions of digital technologies and the frequency of their actual use. While 69.4% of educators agreed that digital tools facilitate the learning of calculus topics and a further 27.8% partially agreed, only 16.7% reported using digital technologies daily and 22.2% weekly, whereas 50.0% used them only occasionally. Previous technology-related training was also limited, with 22.2% of educators reporting that they had received such training. The most frequently reported barriers included technical problems, limited access to technology, the cost of digital content and resources, insufficient training, and a lack of methodological guidance. At the same time, visualization and increased student engagement were among the most frequently reported benefits of using digital technologies.

PCA of the educator data retained five components that together explained 35.52% of total variance: PC1, 9.52%; PC2, 7.86%; PC3, 6.81%; PC4, 5.83%; and PC5, 5.50% (fig. 2). The low cumulative variance and small educator sample mean that the components should be interpreted as exploratory patterns rather than as a stable or comprehensive latent structure. A one-way ANOVA

then compared the three score-derived profiles ($n = 20, 12$, and 4). The omnibus results were PC1, $F(2, 33) = 50.14$, $p < .001$, $\eta^2 = .752$; PC2, $F(2, 33) = 20.69$, $p < .001$, $\eta^2 = .556$; PC3, $F(2, 33) = 0.02$, $p = .980$, $\eta^2 = .001$; PC4, $F(2, 33) = 5.84$, $p = .0068$, $\eta^2 = .261$; and PC5, $F(2, 33) = 0.96$, $p = .393$, $\eta^2 = .055$ (table 2). Levene's tests were non-significant (all $p > .69$). The significant tests indicate differences in component scores between the empirically derived profiles; they do not show that PC1, PC2, or PC4 are more influential. Moreover, because profile membership was derived from the same component scores, the ANOVA results are interpreted as descriptive rather than confirmatory.

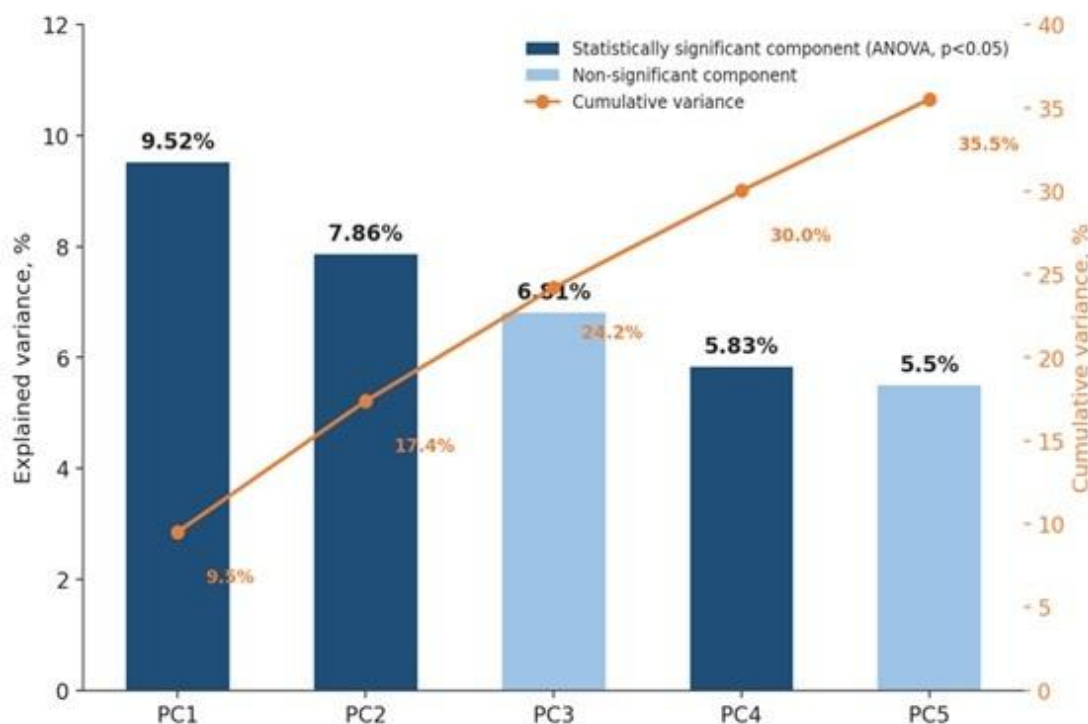


Figure 2. Variance explained by five principal components (PCA). Total 35.52%
Source: compiled by the authors.

Table 2. Variance explained by the five principal components

Component	F	p	η^2
PC1	F(2,33)=50.14	< .001	.752
PC2	F(2,33)=20.69	< .001	.556
PC3	F(2,33)=0.02	.980	.001
PC4	F(2,33)=5.84	.0068	.261
PC5	F(2,33)=0.96	.393	.055

Source: compiled by the authors.

Note: F is the ANOVA test statistic representing the ratio of between-group to within-group variation. The p-value indicates the statistical significance of the observed group differences, with $p < .05$ considered statistically significant. η^2 (eta squared) represents the effect size and indicates the proportion of variance in component scores associated with differences between the three educator profiles.

The first principal component (PC1) represented a professional and institutional dimension of technology integration. The major contributors to the component included variables related to teaching experience, educational background, and school type. Rather than implying that technology use depends on any particular variable, the findings indicate that digital technology integration occurs within a broader context involving educators' professional characteristics and institutional

environment. The component therefore reflects an association between professional and institutional characteristics and patterns of technology integration rather than the effect of any individual characteristic.

The second principal component (PC2) was shown to reflect the connection between the curriculum contents, perceived conceptual complexity, and instructional decisions. Respondents expressed divergent opinions on the question of the right grade level for the introduction of advanced calculus topics, including differential equations. In addition, digital technologies were uniformly evaluated as useful in facilitating the elaboration of difficult mathematical materials. These results suggest that the perceived educational value of technology is related not only to the technology itself but also to the complexity of the educational content. This suggests that interactive visualization may be particularly relevant when educators work with conceptually demanding mathematical content.

PC4 reflected a pattern related to instructional support and professional development. Respondents emphasized seminars, workshops, online training courses, methodological guidance, and digital mathematics software such as GeoGebra, Desmos, and Wolfram Alpha as valuable resources for improving teaching practice and increasing student engagement. Although the statistical effect associated with PC4 was less pronounced than those observed for PC1 and PC2, this component highlights an association between technology integration and opportunities for continuous professional learning that support educators' technological and pedagogical competence.

Taken together, the three statistically significant components suggest that digital technology integration in calculus education is a multidimensional phenomenon associated with professional, instructional, and contextual characteristics rather than with technology availability alone. PC1 reflects associations with educators' professional characteristics and institutional environment, PC2 connects technology integration with perceptions of mathematical content and instructional decisions, and PC4 highlights the role of professional development and methodological support.

These findings are broadly consistent with previous research on technology integration in mathematics education. The educational value of digital technologies depends on how effectively they are embedded within mathematical tasks and classroom practice, while Fitriati (2019) emphasized the importance of teachers' technological and pedagogical competence [4, p. 97]. The present study extends these perspectives by identifying an exploratory pattern in which educators' professional and institutional characteristics are associated with technology integration.

The interpretation of PC2 further supports previous evidence suggesting that digital technologies are particularly beneficial when learners are required to connect symbolic, graphical, and numerical representations of mathematical concepts. Earlier studies have reported similar advantages for teaching derivatives, integrals, and other abstract calculus topics [3, p. 145]. The present findings reinforce this conclusion by showing that perceptions of curriculum complexity and decisions regarding the appropriate educational level for introducing advanced topics form part of the same underlying dimension. This suggests that the pedagogical role assigned to digital technologies is closely related to the nature of the mathematical content being taught.

The pattern represented by PC4 is also related to professional development and methodological support. Opportunities to participate in workshops, methodological training, and collaborative learning activities may support educators' capacity to integrate technology effectively into mathematics instruction. This interpretation is consistent with studies highlighting the contribution of dynamic visualization tools and interactive digital learning environments to both teacher practice and student learning [4, p. 96].

The findings should also be interpreted within the broader educational context of Kazakhstan. Joshkun et al. (2024) demonstrated that students' digital competence is influenced not only by technological resources available in schools but also by their digital experiences beyond formal education [5, p. 15]. This perspective provides additional context for the differences observed between educators' and learners' perceptions in the present study and supports the conclusion that access to technology alone is insufficient to explain meaningful technology integration. Instead, meaningful integration appears to be associated with institutional support, professional expertise, curriculum characteristics, and learners' broader digital environment.

Overall, the findings suggest that digital technology integration in calculus education is associated with broader professional, instructional, and contextual patterns identified in educators' responses. These results shift the discussion beyond technology availability alone and highlight the importance of considering the educational context in which digital technologies are used. Such a perspective may inform the design of professional development programmes and methodological support aimed at promoting meaningful uses of digital technologies in mathematics education.

Limitations. The study has several limitations. First, although the survey included 176 respondents, the multivariate analysis was conducted only on the educator subsample ($n = 36$). The small educator sample limits the generalizability and stability of the exploratory PCA results. In addition, one of the three empirically derived educator profiles included only four participants. The findings should therefore be interpreted cautiously and examined further in larger and more diverse educator samples.

Second, self-reported questionnaire data was used in this study. The data offered insight into the participants' perceptions and experiences on the topic, but this may not precisely reflect classroom practices. By combining self-reported data with classroom observation, interview, or learning analytics, one can obtain much richer insights into the practical application of digital technologies in calculus instruction.

Third, the study employed a cross-sectional research design. Consequently, the identified relationships should be interpreted as associations rather than causal effects. Longitudinal studies would enable researchers to examine how teachers' professional development, institutional support, and technology integration evolve over time.

Finally, the present research focused on identifying broad patterns associated with digital technology integration rather than evaluating the effectiveness of specific digital tools or instructional approaches. Future studies could investigate how particular technologies, such as dynamic mathematics software, computer algebra systems, or artificial intelligence-supported learning environments, influence students' conceptual understanding, problem-solving skills, and long-term learning outcomes.

In addition, the five retained principal components explained 35.52% of the total variance. Consequently, a substantial proportion of variability remained outside the retained solution, and the component structure should be regarded as exploratory.

Regardless of these limitations, the present study contributes to the expanding body of research on technology integration in the teaching of mathematics. The findings suggest that technology use in calculus instruction is associated with a combination of professional, pedagogical, and contextual characteristics rather than with access to technology alone. The findings may inform the development of professional development programmes and methodological support for digital technology integration in mathematics education.

Conclusion. The study examined factors associated with digital technology integration in calculus education. The findings suggest that technology integration is related to a combination of professional, instructional, and contextual characteristics rather than to the availability of digital resources alone. The exploratory PCA identified dimensions involving educators' professional and institutional characteristics, perceptions of mathematical content and instructional decisions, as well as professional development and methodological support. The descriptive results further showed that educators generally perceived digital technologies positively, although their reported frequency of use and previous technology-related training varied considerably.

The findings show that the integration of digital technologies into calculus education should be considered in relation to the conditions in which teaching and learning take place. Providing digital tools is important, but their meaningful use should also be considered in relation to educators' professional preparation, the mathematical content being taught, and the methodological support available to teachers. The results therefore support the inclusion of a dedicated digital technology component in the course "Innovative Approaches to Teaching Differential and Integral Calculus," with particular attention to the use of digital resources for visualization and the teaching of conceptually demanding topics.

Further research could examine these relationships using larger and more diverse samples and investigate how particular approaches to technology integration affect students' conceptual understanding and mathematical reasoning over time.

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МАТЕМАТИКАЛЫҚ АНАЛИЗДІ ОҚЫТУ КОНТЕКСТІНДЕ МАТЕМАТИКАЛЫҚ БІЛІМ БЕРУГЕ ЦИФРЛЫҚ ТЕХНОЛОГИЯЛАРДЫ КІРІКТІРУ ФАКТОРЛАРЫ

Аннотация

Зерттеудің мақсаты математикалық анализді оқыту мысалында математикалық білім беруге цифрлық технологияларды кіріктіру факторларын анықтау болып табылады. Зерттеуде 176 респонденттің сауалнама деректері пайдаланылды, олардың 36-сы математика пәнінің оқытушылары, ал 140-ы математикалық анализді немесе оның негіздерін оқып жүрген білім алушылар. Деректерді талдау барысында негізгі компоненттер әдісі (PCA) мен дисперсиялық талдау (ANOVA) пайдаланылды. PCA нәтижесінде жалпы дисперсияның 35,52%-ын түсіндіретін бес компонент анықталып, олардың үшеуі бойынша статистикалық мәнді айырмашылықтар байқалды. Анықталған компоненттер оқытушылардың кәсіби және институционалдық сипаттамаларын, математикалық мазмұнды қабылдау мен оқытуды ұйымдастыру ерекшеліктерін, сондай-ақ кәсіби даму мен әдістемелік қолдауды қамтиды. Цифрлық құралдар математикалық ұғымдарды көрсету және абстрактілі идеяларды түсіндіру тұрғысынан жалпы оң бағаланғанымен, оларды қолдану деңгейі білім беру жағдайларына қарай ерекшеленеді. Алынған нәтижелер цифрлық технологияларды тиімді кіріктіру тек цифрлық ресурстардың болуымен ғана емес, оларды қолданудың кәсіби, әдістемелік және білім беру жағдайларымен де байланысты екенін көрсетеді. Зерттеу нәтижелерін математикалық білім беру саласында әдістемелік материалдар мен оқытушылардың кәсіби даму бағдарламаларын әзірлеуде пайдалануға болады.

Түйінді сөздер: математикалық анализді оқыту, цифрлық технологияларды кіріктіру, математикалық білім беру, цифрлық құзыреттілік, кәсіби даму, цифрлық құралдар, дифференциалдық және интегралдық есептеулер, білім алушылардың белсенділігі.

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ФАКТОРЫ ИНТЕГРАЦИИ ЦИФРОВЫХ ТЕХНОЛОГИЙ В МАТЕМАТИЧЕСКОЕ ОБРАЗОВАНИЕ В КОНТЕКСТЕ ПРЕПОДАВАНИЯ МАТЕМАТИЧЕСКОГО АНАЛИЗА

Аннотация

Цель исследования заключается в выявлении факторов интеграции цифровых технологий в математическое образование на примере преподавания математического анализа. В исследовании использованы данные анкетирования 176 респондентов, в том числе 36 преподавателей математики и 140 обучающихся, изучающих математический анализ или его основы. Для анализа данных применялись метод главных компонент (PCA) и дисперсионный анализ (ANOVA). В результате PCA было выделено пять компонентов исследовательского характера, объясняющих 35,52% общей дисперсии, для трех из которых были выявлены статистически значимые различия. Выделенные компоненты отражают профессиональные и институциональные характеристики, восприятие содержания математического материала и особенности организации обучения, а также профессиональное развитие и методическую поддержку преподавателей. Цифровые инструменты в целом положительно оцениваются с точки зрения представления математических понятий и объяснения абстрактных идей, однако интенсивность их использования различается в зависимости от образовательного контекста. Полученные данные свидетельствуют о том, что эффективная интеграция цифровых технологий связана не только от наличия цифровых ресурсов, но и от профессиональных, методических и образовательных условий их применения. Результаты исследования могут быть использованы при разработке методических материалов и программ профессионального развития преподавателей в области математического образования.

Ключевые слова: обучение математическому анализу, интеграция цифровых технологий, математическое образование, цифровая компетентность, профессиональное развитие, цифровые инструменты, дифференциальное и интегральное исчисление, вовлеченность обучающихся.

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