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PSYCHOLOGICAL AND PEDAGOGICAL FEATURES OF MATHEMATICAL EDUCATION IN GENERAL EDUCATION SCHOOLS IN THE CONTEXT OF DIGITALIZATION

Abstract

This article is devoted to the study of the psychological and pedagogical features of the process of studying ordinary fractions in secondary schools in the context of digitalization of education. The aim of the study is to identify the impact of digital tools and information and communication technologies (ICT) on the cognitive, motivational and emotional development of students studying the topic «Ordinary fractions». Based on the research results, effective psychological and pedagogical approaches to their application have been identified.

The study used quantitative and qualitative methods: student questionnaires (n = 452), knowledge testing before and after the introduction of digital forms of education, pedagogical observation, and statistical data for the period 2021-2025 were analyzed by the authors. The empirical basis of the study is based on the material of secondary schools in the Russian Federation, with subsequent interpretation of the results in the context of the secondary education system of the Republic of Kazakhstan.

The results of the statistical analysis show that the use of digital platforms and interactive tools increases the average academic performance of students by 12-18%, helps to reduce learning anxiety and form more stable cognitive representations of ordinary fractions. The practical significance of the work describes the development of methodological recommendations for the integration of digital resources into the teaching of mathematics, taking into account the psychological and pedagogical characteristics of students and the specifics of the digitalization of education in Kazakhstan.

Keywords: digitalization, mathematical education, digital infrastructure, ordinary fractions, learning motivation, secondary school, regression model.

Introduction. The study of ordinary fractions is one of the keys and at the same time the most difficult sections of the school mathematics course. The difficulties of mastering this topic are related to the abstraction of the concepts of «part-whole», operations of comparison, transformation and performing arithmetic operations with fractions. These difficulties are compounded by cognitive overload, insufficient visualization, and high learning anxiety among students.

In the context of digitalization of education, the school system faces new challenges related to the introduction of digital educational resources, interactive platforms and adaptive learning technologies. In the Republic of Kazakhstan, the processes of digital transformation of education are developing within the framework of state programs («Digital Educational Environment», «Digital Kazakhstan»), which creates a common methodological and infrastructural field for comparing the pedagogical effects of digital learning [1].

In the Republic of Kazakhstan, the issues of digitalization of school education are becoming particularly relevant in connection with the implementation of the state programs «Digital Kazakhstan» and «Digital School» aimed at improving the quality of education, developing digital competencies of students and equalizing educational opportunities between regions. At the same time, the problem of forming stable mathematical concepts, including on the topic of «Ordinary fractions», remains one of the most difficult in the practice of teaching mathematics in secondary schools.

The reference to the experience of the Russian Federation and the People's Republic of China in this study is analytical in nature and is conditioned by the need to compare different models of digitalization of education. Russia provides an example of an educational system that is similar in content to curricula and methodological approaches, while China demonstrates a high degree of consistency and scale of the introduction of digital educational technologies [2]. Comparing these

approaches allows for a deeper understanding of the prospects and limitations of digitalization of mathematics education in the Republic of Kazakhstan. The analyses of neighboring countries also show the development of Kazakhstan's educational trends, which can become a valuable foreign experience for the country.

Methods and materials. The study was conducted in 2021-2025 and was quasi-experimental in nature. The main empirical part of the study was focused on the analysis and generalization of data relevant to the system of general secondary education in the Republic of Kazakhstan. Empirical data were compared with the results of similar studies conducted in the Russian Federation and the People's Republic of China, which allowed us to consider the impact of digital educational technologies in various models of digitalization of education [3]. In addition, the use of artificial intelligence and big data allows you to visually present the results of the analysis.

In Kazakhstan, the processes of digitalization of education are implemented taking into account the infrastructural differentiation of schools, differences between urban and rural educational organizations, as well as the level of digital competence of teaching staff. The availability of Internet infrastructure, multimedia classrooms, and access to educational platforms such as Kundelik.kz, BilimLand, OnlineMektep and other digital educational resources.

In domestic studies, it is noted that the digitalization of education in Kazakhstan is a step-by-step process and requires methodological support from teachers when introducing digital educational technologies into the educational process. According to a number of Kazakhstani researchers, digital technologies are most effective when they are integrated into the traditional pedagogical system, rather than completely replacing classical teaching methods.

The present study is aimed at solving the national scientific and practical problem of improving the quality of mathematical education in the context of the digitalization of schooling in the Republic of Kazakhstan by identifying psychological and pedagogical mechanisms for the formation of mathematical concepts in the study of the topic «Ordinary fractions».

The methodological tools of the research were adapted to the national educational context. The survey was conducted in Kazakh and Russian, which ensured the cultural and linguistic validity of diagnostic procedures. Regional peculiarities of the educational environment of schools were also taken into account, including differences in the technical equipment of educational organizations and the level of digital readiness of students and teachers.

The study involved 452 pupils of grades 5-7 of secondary schools of the Republic of Kazakhstan, representing the municipal government institutions «Secondary School № 15» and «Secondary School № 102» in Almaty, as well as «Secondary School № 12 named after A. Baitursynov» Zhetisu region. The sample included 232 students from the experimental group and 220 students from the control group. The groups were selected according to the principle of equivalence – according to age, the level of basic mathematical education and the socio-economic status of the families. The experimental group studied using digital tools, while the control group studied in a traditional face-to-face manner without using interactive technologies.

The experimental group used digital resources such as educational platforms, as well as simulators and interactive applications «GeoGebra», Phet «Fraction Lab», digital simulators and fraction visualizers. These tools allowed us to model fractions, perform operations with them, visually observe the processes of addition and subtraction of fractions with the same and different denominators, as well as form ideas about the relationship between ordinary and decimal fractions.

The experiment took place in three main stages. At the first stage (diagnostic), students of both groups passed an entrance test on the topic «Ordinary fractions» (maximum 30 points), a questionnaire on the level of educational motivation (A. A. Rean's method) and anxiety (modified Phillips scale). At the second stage (formative), the training was conducted using various methodological strategies: traditional explanatory and illustrative methods for the control group, digital interactive forms (virtual laboratories, visualization, game tasks, adaptive simulators) for the experimental group [4]. The duration of the formative stage was eight weeks. At the third stage (control), final testing and repeated questionnaires were conducted, aimed at identifying changes in cognitive and emotional indicators.

To obtain additional data, methods of pedagogical observation, interviews with teachers and an analysis of the portfolio of digital achievements of students were used. The collected data was subjected to statistical processing using the SPSS (statistical package for the social sciences) Statistics 27 package and the Python language (pandas' module, SciPy (scientific python). Stats). The methods of correlation and regression analysis, t-test for independent samples and ANOVA (analysis of variance) were used. The statistical significance level is assumed to be $p < 0,05$. To verify the consistency of the questionnaire scales, the Kronbach reliability coefficient ($\alpha = 0,82$) was used, which confirms the internal consistency of diagnostic indicators.

To quantify the closeness and directionality of the relationships between variables, the Pearson linear correlation coefficient was calculated using the formula (1):

$$r = \frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\overline{x})^2 * \sum(y_i-\overline{y})^2}} \qquad (1)$$

Where x_i – values of the first variable (for example, the level of educational motivation), y_i – values of the second variable (test results), $\overline{x}, \overline{y}$ – the average values of the corresponding indicators, n – the sample size. The regression model is calculated using the formula (2):

$$Y = \beta_0 + \beta_1 X + \varepsilon \qquad (2)$$

where Y is academic performance, X is the frequency of use of digital resources, β_1 is the regression coefficient, ε is the model error.

In addition to quantitative methods, special attention was paid to qualitative data analysis. Teachers recorded observations of students' behavior, their level of engagement, degree of independence, and emotional response to digital tasks. Examples of student work were analyzed separately – screenshots of solutions, dynamics of exercises, and comments left on digital platforms. This allowed us to establish that students more often resort to reasoning and experimentation when using interactive visualizers, which contributes to the formation of stable conceptual structures.

International data sources were used for comparative analysis. In particular, the official reports of the Ministry of Education of the People's Republic of China (2022-2025) and UNESCO (2023) were used, according to which more than 99,5% of Chinese schools have multimedia equipment and access to digital educational resources [5]. For Russia, the same indicator was 85% by 2024, which indicates a high but still uneven level of digitalization of the educational process [6].

The statistical calculations made it possible to establish a significant positive correlation between the activity of using digital tools and the success of mastering the topic «Ordinary fractions» ($r = 0,42$, $p < 0,05$). Regression analysis showed that an increase in the degree of digitalization of the lesson by one unit on the scale of digital engagement assessment leads to an increase in the average test result by 0,35 points. The data obtained confirm that digital technologies have a natural, rather than accidental, impact on the process of mathematical knowledge formation and contribute to the activation of cognitive activity of students.

The use of a comparative international context made it possible to identify the universal and specific psychological and pedagogical effects of digitalization of mathematics education, as well as to identify factors of the greatest practical importance for the education system of the Republic of Kazakhstan.

To identify the interrelationships between the educational performance indicators of secondary school students in the Republic of Kazakhstan, a correlation analysis was conducted. The following variables were considered as analyzed variables: the level of learning motivation, the level of learning anxiety, and the test results on the topic of «Ordinary fractions».

The analysis showed a statistically significant positive correlation between the level of educational motivation and the learning outcomes of students in the experimental group of secondary schools in the Republic of Kazakhstan (as 0,46 $r = 0,46$, $p < 0,05$ $p < 0,05$). This indicates that an

increase in students' learning motivation is accompanied by an increase in the success of mastering mathematical material when using digital educational resources.

At the same time, a negative correlation was found between the level of learning anxiety and test results ($r = - 0,41$ $r= - 0,41$, $p < 0,05$ $p < 0,05$), indicating a decrease in academic achievement with an increase in student anxiety.

In addition, an analysis of the relationship between learning motivation and learning anxiety showed a moderate negative correlation ($r = - 0,38$ $r = - 0,38$, $p < 0,05$ $p < 0,05$), which allows us to conclude that motivation plays a compensatory role in reducing the negative emotional background of learning activities.

The obtained correlations confirm that in the conditions of secondary schools in the Republic of Kazakhstan, the use of digital educational resources has a direct and indirect impact on learning outcomes. The direct impact is manifested through improving the quality of learning material, and indirectly through changing the psychological characteristics of students' learning activities.

Unlike several Kazakhstan studies, in which the analysis is limited to describing the pedagogical effects of digital technologies, the presented results are based on a quantitative assessment of the relationships between key indicators of educational activity, which allows us to talk about the systemic nature of the identified patterns.

Results and discussion. Table 1 shows the average (M) and standard deviations (SD) of academic performance (test of ordinary fractions) in the experimental and control groups before and after the introduction of digital learning.

Table 1. Test results on the topic «Ordinary fractions» (scores out of 30)

Group	Time	M	SD
Control (traditional)	Before	17,4	4,2
Control	After	19,1	4,1
Experiment (digital)	Before	17,6	4,3
Experiment	After	21,4	3,8

Source: Compiled by the authors

The t-test analysis of independent samples showed that the difference between the groups after training (control vs experiment) is significant: $t (450) = 4,67$, $p < 0,001$. The average increase in the experimental group was 3,8 points (≈ 12,7%), which is significantly higher than the increase in the control group (1,7 points ≈ 9,8%). Correlation analysis showed $r = 0,42$ between the degree of use of digital tasks and the final score, which indicates a moderate positive relationship. The regression model showed $\beta_1 = 0,35$ ($p < 0,01$), that is, an increase in the degree of use of a digital instrument by one (on a scale) leads to an increase in the score by 0,35.

To visually represent the dynamics of academic performance on the topic of «Ordinary fractions» in the control and experimental groups, comparative diagrams were constructed. Figure 1 shows the average test results (in points) before and after training in both groups (Figure 1).

After analyzing the data presented in Figure 1, it can be noted that digital learning led to a significant increase in results – the average score in the experimental group increased by 3,8 (≈12,7%), while in the control group it increased by only 1,7 (≈9,8%). The differences obtained are statistically significant ($t(450) = 4,67$, $p < 0,001$), which confirms the hypothesis of the study on the positive impact of digitalization on the quality of learning the topic «Ordinary fractions».

In addition, the questionnaires showed a decrease in anxiety: the average score on the anxiety scale decreased from 3,2 ($SD = 0,74$) to 2,7 ($SD = 0,68$) in the experimental group. Student motivation increased: the proportion of students who answered «yes» to the question «I'm interested in learning fractions using a digital tool» increased from 42% to 63%. A comparative analysis with the Chinese experience shows the following features: in China, by 2021, the entire list of schools (100%) was connected to the Internet and 99,5% had multimedia classrooms. This has created a favorable infrastructure for digital learning. The presented Russian study also shows that the availability of home appliances and Internet access increase the effectiveness of digital learning (the covariate

turned out to be significant: $f = 5{,}12$, $p < 0{,}05$). However, cultural and pedagogical differences have emerged: Chinese studies note a higher correct adaptation of digital platforms and a more systematic introduction of «smart classrooms».

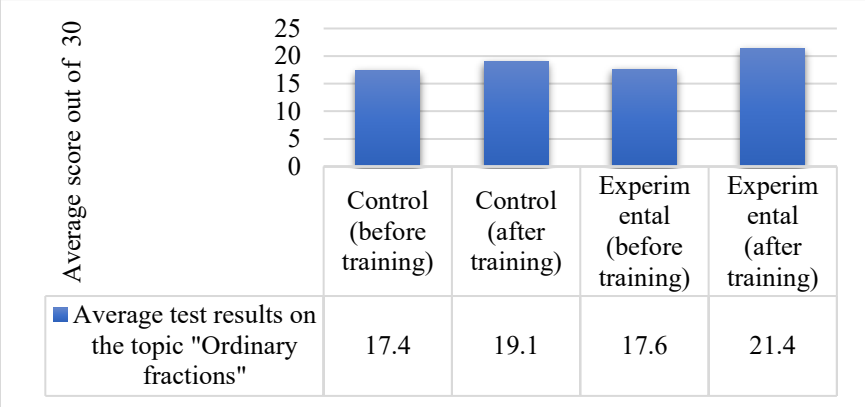

Figure 1. Comparison of test results on the topic «Ordinary fractions» in the control and experimental groups (before and after training).

Source: Compiled by the authors

During the experiment, a significant improvement in results was recorded in the experimental group, which confirms the effectiveness of using digital tasks in the learning process. In the control group, the score increase was significantly lower, which underscores the importance of using new technologies in the educational process. The analysis showed a positive relationship between the use of digital tools and the improvement of knowledge. This indicates that such tools contribute to deeper learning of the material.

Prior to the start of the experiment, the indicators of the two groups practically did not differ, which confirms their equivalence in terms of the level of initial knowledge. After conducting digital learning in the experimental group, there is a noticeable increase in the average score, which indicates the effectiveness of using digital tools in studying the topic. The analysis data confirms that an increase in the use of such tools contributes to an increase in the effectiveness of the educational process. This approach is becoming increasingly relevant for improving the quality of education.

Discussing the data obtained, the following psychological and pedagogical features can be distinguished:

1) visualization and interactivity of fractions through digital means (animations, virtual manipulators) they contribute to the better formation of «part-whole» ideas and reduce cognitive load.

2) The personalization of tasks and the adaptability of the platform make it possible to take into account an individual pace, which is especially important for the topic of fractions, where students with different levels of training enter the topic.

3) Anxiety reduction is due to the fact that the digital environment offers real-time feedback, which reduces the fear of mistakes and increases confidence.

4) nevertheless, a convention has been revealed: without pedagogical support, correct methodological support and teacher training, digital tools do not give the expected effect – as evidenced by foreign reviews.

5) the learning context (availability of home appliances, Internet access, self-organization skills among students) significantly affects the effectiveness of digitalization, which is confirmed by data from Russia/To China.

A comparison with the Chinese experience shows that a large-scale infrastructure base and a single platform (for example, the Smart Education of China platform) create conditions for systemic digitalization. Therefore, the introduction of digital fraction learning tools should be accompanied by a teacher training strategy, student support organization, and digital access alignment [7].

In general, the results confirm the hypothesis that digital learning tools contribute to improving the understanding of fractions and have a significant psychological and pedagogical effect [8].

However, an integrated approach is needed: technical support + methodology + teacher training + consideration of territorial and socio-economic characteristics of students [9].

An analysis of international experience shows that for Kazakhstan, the most productive model is step-by-step and methodically accompanied digitalization, combining elements of Russian practice (adapting digital platforms to the school curriculum) and the Chinese approach (consistency and integration of digital tools into the educational process). This combination makes it possible to consider the national peculiarities of the educational system and the real conditions of functioning of schools.

The results of the study confirm that the introduction of digital tools in the study of fractions helps to reduce learning anxiety, increase learning motivation and form stable mathematical concepts, which is especially important for Kazakhstan in the context of improving functional literacy of students and the results of international comparative studies.

The revealed correlations in the Kazakh sample in terms of focus and strength are comparable to the results of studies conducted in the Russian Federation and the People's Republic of China, which also show a positive relationship between learning motivation and academic achievement and a negative relationship between learning anxiety and learning outcomes when using digital educational resources.

Conclusion. The conducted research allowed us to confirm the importance of digital technologies as one of the factors of increasing the effectiveness of mathematical education in modern schools in the Republic of Kazakhstan. It has been established that the integration of digital educational resources contributes to the creation of a more comfortable and differentiated educational environment that supports students' cognitive activity in the study of abstract mathematical concepts.

The results show that the digitalization of learning has a complex impact on the educational process, affecting not only the cognitive sphere of students, but also the motivational and emotional aspects of learning activities [10]. An important condition for the effectiveness of digital tools is their methodically sound use, as well as the availability of pedagogical support aimed at developing self-regulation and independent cognition skills.

The scientific novelty of the study is to identify the psychological and pedagogical mechanisms of the influence of the digital educational environment on the formation of mathematical representations in the study of ordinary fractions. The analysis made it possible to determine that the greatest educational effect is achieved with a combination of technological innovations, professional training of teachers and taking into account the socio-educational conditions of schools. A comparison of the results obtained with the Chinese experience of digital transformation of education revealed common trends and significant differences. In China, digitalization is systematic, which ensures high consistency between infrastructure, methodology and teaching practice. The Russian experience demonstrates significant potential, but its implementation is often limited by uneven technical support for schools and insufficient teacher training [11]. At the same time, there is a steady development of teachers' digital competence, which creates conditions for the gradual formation of a unified educational digital space.

In the psychological and pedagogical aspect, digitalization of learning ordinary fractions contributes to the creation of a comfortable, motivating and differentiated educational environment [12]. The visual and interactive nature of digital tools allows students to perceive abstract mathematical concepts through actions, experiments, and modeling, making the learning process more meaningful and accessible. At the same time, digital learning is not a substitute for the traditional methodology, but its development and complement, ensuring the transition to a personality-oriented model of education.

The practical conclusions of the study indicate the need for an integrated approach to the digitalization of mathematics education. The introduction of digital resources should be accompanied by methodological support, professional training of teachers, regular monitoring of cognitive and emotional states of students, as well as ensuring equal access to technology and the Internet. It is important that digital technologies are used not sporadically, but systematically, as part of an integrated pedagogical process. Only with a combination of technological and psychological-

pedagogical conditions is it possible to achieve a sustainable improvement in the quality of mathematical education.

The multiplicative effect of digitalization of mathematics education for the Republic of Kazakhstan is manifested in the possibility of scaling the identified pedagogical solutions to various levels and types of schools without significantly increasing resource costs. The use of digital platforms and interactive models makes it possible to improve the quality of education, reduce the burden on teachers and at the same time create conditions for the individualization of the educational process.

In the future, this area may become the basis for the development of integrated methodological complexes on other topics of the school mathematics course. Digital forms of information representation, the use of interactive models and gamification elements can significantly expand the teacher's capabilities in individualizing and humanizing learning.

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ЦИФРЛАНДЫРУ ЖАҒДАЙЫНДА ЖАЛПЫ БІЛІМ БЕРЕТІН МЕКТЕПТЕРДЕГІ МАТЕМАТИКАЛЫҚ БІЛІМ БЕРУДІҢ ПСИХОЛОГИЯЛЫҚ-ПЕДАГОГИКАЛЫҚ ЕРЕКШЕЛІКТЕРІ

Аңдатпа

Бұл мақала білім беруді цифрландыру жағдайында жалпы білім беретін мектептердегі қарапайым бөлшектерді зерттеу процесінің психологиялық-педагогикалық ерекшеліктерін зерттеуге арналған. Зерттеудің мақсаты цифрлық құралдар мен ақпараттық-коммуникациялық технологиялардың (АКТ) «Қарапайым бөлшектер» тақырыбын зерттеу кезінде оқушылардың танымдық, мотивациялық және эмоционалдық дамуына әсерін анықтау болып табылады. Зерттеу нәтижелері бойынша оларды қолданудың тиімді психологиялық-педагогикалық тәсілдері анықталды.

Зерттеуде сандық және сапалық әдістер қолданылды: оқушыларға сауалнама жүргізу (N = 452), оқытудың цифрлық нысандарын енгізгенге дейін және одан кейінгі білімді тестілеу, педагогикалық бақылау және авторлармен 2021-2025 жылдар кезеңіндегі статистикалық деректерді талданды. Зерттеудің эмпирикалық базасы Ресей Федерациясының орта мектептерінің материалына негізделген, содан кейін нәтижелерді Қазақстан Республикасының орта білім беру жүйесі контекстінде түсіндіреді.

Статистикалық талдау нәтижелері цифрлық платформалар мен интерактивті құралдарды пайдалану оқушылардың орташа үлгерімін 12-18% - ға арттыратынын, оқу мазасыздығын төмендетуге және қарапайым фракциялар туралы неғұрлым тұрақты когнитивті түсініктерді қалыптастыруға ықпал ететінін көрсетеді. Жұмыстың практикалық маңыздылығында оқушылардың психологиялық-педагогикалық ерекшеліктерін және Қазақстандағы білім беруді цифрландыру ерекшеліктерін ескере отырып, математиканы оқытуға цифрлық ресурстарды интеграциялау бойынша әдістемелік ұсынымдар әзірлеу сипатталған.

Түйінді сөздер: цифрландыру, математикалық білім беру, цифрлық инфрақұрылым, қарапайым фракциялар, оқуға ынталандыру, орта мектеп, регрессия моделі.

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ПСИХОЛОГО-ПЕДАГОГИЧЕСКИЕ ОСОБЕННОСТИ МАТЕМАТИЧЕСКОГО ОБРАЗОВАНИЯ В ОБЩЕОБРАЗОВАТЕЛЬНЫХ ШКОЛАХ В УСЛОВИЯХ ЦИФРОВИЗАЦИИ

Аннотация

Данная статья посвящена исследованию психолого-педагогических особенностей процесса изучения обыкновенных дробей в общеобразовательных школах в условиях цифровизации образования. Целью исследования является выявление влияния цифровых инструментов и информационно-коммуникационных технологий (ИКТ) на когнитивное, мотивационное и эмоциональное развитие учащихся при изучении темы «Обыкновенные дроби». По результатам исследований выявлены эффективные психолого-педагогические подходы к их применению.

В исследовании использовались количественные и качественные методы: сделаны анкетирование учащихся (n = 452), тестирование знаний до и после внедрения цифровых форм обучения, педагогическое наблюдение и проанализированы авторами статистические данные за период 2021–2025 годов. Эмпирическая база исследования основана на материале средних школ Российской Федерации с последующей интерпретацией результатов в контексте системы среднего образования Республики Казахстан.

В результатах статистического анализа показано, что использование цифровых платформ и интерактивных инструментов повышает среднюю успеваемость учащихся на 12-18%, способствует снижению учебной тревожности и формированию более устойчивых когнитивных представлений об обыкновенных дробях. В практической значимости работы описаны разработки методических рекомендаций по интеграции цифровых

ресурсов в преподавание математики с учетом психолого-педагогических особенностей учащихся и специфики цифровизации образования в Казахстане.

Ключевые слова: цифровизация, математическое образование, цифровая инфраструктура, обыкновенные дроби, мотивация к обучению, средняя школа, регрессионная модель.

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