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THE IMPACT OF INTERACTIVE ENVIRONMENTS (GEOGEBRA/DESMOS) ON THE DEVELOPMENT OF STUDENTS' MATHEMATICAL COMPETENCIES: A PEDAGOGICAL AND PSYCHOLOGICAL ANALYSIS

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Abstract: This article analyzes the pedagogical and psychological aspects of using interactive digital environments such as GeoGebra and Desmos in developing students' mathematical competencies. In modern education, it is important not only to acquire theoretical mathematical knowledge but also to develop the ability to apply this knowledge in practical situations, create mathematical models, independently solve problem-based tasks, and justify the obtained results.

The article argues that the purposeful and methodologically appropriate use of interactive digital environments contributes to the development of students' mathematical competencies, supports their learning motivation, and encourages active participation in mathematics classes.

Key words: mathematical competence, interactive learning environment, GeoGebra, Desmos, digital technologies, mathematical thinking, visualization.

Аннотация: В данной статье анализируются педагогические и психологические аспекты использования интерактивных цифровых сред, таких как GeoGebra и Desmos, в процессе развития математических компетенций студентов. В современном образовательном процессе важное значение имеет не только теоретическое усвоение математических знаний, но и формирование умений применять их в практических ситуациях, создавать математические модели, самостоятельно решать проблемные задачи и обосновывать полученные результаты. В статье обосновывается, что целенаправленное и методически грамотное использование цифровой интерактивной среды способствует развитию математических компетенций студентов, поддержанию учебной мотивации и повышению их активного участия в занятиях по математике.

Ключевые слова: математическая компетентность, интерактивная образовательная среда, GeoGebra, Desmos, цифровые технологии, математическое мышление, визуализация.

Annotatsiya: Ushbu maqolada talabalarning matematik kompetensiyalarini rivojlantirish jarayonida GeoGebra va Desmos kabi interaktiv raqamli muhitlardan foydalanishning pedagogik hamda psixologik jihatlari tahlil qilinadi. Zamonaviy ta'lim jarayonida matematik bilimlarni faqat nazariy shaklda o'zlashtirish emas, balki ularni amaliy vaziyatlarda qo'llash, matematik modellar yaratish, muammoli masalalarni mustaqil hal qilish va natijalarni asoslab berish ko'nikmalarini shakllantirish muhim ahamiyat kasb etadi. Maqolada raqamli interaktiv muhitdan maqsadli va metodik jihatdan to'g'ri foydalanish talabalarning matematik kompetensiyalarini rivojlantirish, o'quv

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motivatsiyasini qo‘llab-quvvatlash hamda matematika mashg‘ulotlarida faol ishtirokini kuchaytirish imkoniyatlari bilan bog‘liq ekanligi asoslanadi.

Kalit so‘zlar: matematik kompetensiya, interaktiv ta’lim muhiti, GeoGebra, Desmos, raqamli texnologiyalar, matematik tafakkur, vizualizatsiya.

INTRODUCTION

The rapid development of digital technologies has significantly changed approaches to teaching and learning mathematics. Modern mathematics education requires students not only to remember formulas and algorithms but also to understand mathematical relationships, analyze problems, construct mathematical models, interpret data, and apply mathematical knowledge to practical situations. Therefore, the development of mathematical competence has become one of the central objectives of contemporary higher education. Traditional teaching methods may present mathematical concepts mainly through formulas, static diagrams, and teacher explanations. Although these methods remain important, students can experience difficulties when dealing with abstract concepts such as functions, transformations, derivatives, integrals, and geometric relationships. Digital mathematical environments provide additional opportunities to make such concepts observable and interactive. Research on technology-supported mathematics education indicates that digital tools can create environments in which students explore relationships, test assumptions, receive immediate visual feedback, and connect symbolic and graphical representations [1].

GeoGebra is particularly useful because it integrates geometry, algebra, graphing, calculus, and other mathematical representations within a dynamic environment. Students can manipulate mathematical objects and immediately observe how changes in one variable influence other elements. Research synthesizing studies on GeoGebra has reported positive effects on students’ mathematical abilities, while also showing that outcomes depend on factors such as the instructional context, duration, and sample characteristics [2].

Desmos provides similar opportunities through an accessible web-based graphing environment. For example, when studying the quadratic function (y=ax^2+bx+c), students can change the values of (a), (b), and (c) by using sliders. Instead of simply memorizing that the coefficient (a) influences the direction and width of a parabola, students can observe the transformation dynamically. Such experimentation can support the transition from procedural knowledge to conceptual understanding.

LITERATURE REVIEW

The theoretical foundations of technology-supported mathematics teaching emphasize that digital tools are most effective when they are integrated into meaningful mathematical activity rather than used merely as substitutes for traditional calculation. Aldon and Trgalová [3], in *Technology in Mathematics Teaching*, discuss the role of digital technology in transforming mathematical tasks and learning environments. Their work indicates that technology can provide learners with opportunities to experiment with mathematical objects, explore multiple representations, and participate more actively in constructing mathematical meaning.

A second important direction in the literature concerns the dynamic nature of mathematical visualization. The educational value of an interactive mathematical environment lies not simply in displaying a graph but in establishing connections among algebraic, graphical, numerical, and

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geometric representations. A systematic review of GeoGebra research found that studies frequently focused on learning performance, higher-order thinking, students' attitudes and perceptions, particularly in geometry and mathematical analysis [4]. The same review also identified a relative lack of research addressing psychological variables such as cognitive load, anxiety, and engagement, demonstrating the need for a combined pedagogical-psychological approach. Evidence from meta-analytic research further supports the educational potential of GeoGebra. A meta-analysis covering 29 primary studies and 2,111 students reported an overall positive effect of GeoGebra-supported instruction on mathematical abilities [5]. Importantly, this finding does not imply that the software automatically improves learning. Rather, the effectiveness of technology depends on how teachers design tasks, organize interaction, and encourage students to interpret what they observe.

For instance, in a lesson on the function

[
y=x^2-4x+3,
]

a traditional activity may require students to calculate several coordinate points and draw the parabola manually. In an interactive environment, students can graph the function, identify its roots, vertex, and axis of symmetry, and then modify the coefficients. They may be asked: *What happens to the vertex when the coefficient of x changes?* Such a question transforms visualization into mathematical inquiry.

Research focusing on mathematical competence has similarly indicated that GeoGebra can support mathematical understanding, geometric reasoning, and problem-solving [6]. These abilities are interconnected because competent mathematical performance requires students to move beyond obtaining a correct numerical answer and explain why a particular method or result is mathematically valid.

Desmos has also attracted increasing attention in mathematics education. Research involving algebra instruction found that the integration of Desmos with lessons and homework supported students' post-test performance and concept retention and was associated with increased interest and practice [7]. Another study involving undergraduate learners investigated the use of Desmos for exponential and logarithmic functions and highlighted its role as a technology-supported environment for exploring these mathematical concepts [8]. Graphing technology has a longer research history beyond individual applications. Ellington's meta-analysis examined 42 studies concerning graphing calculators and students' mathematics achievement and attitudes [9]. Such research provides an important foundation for understanding contemporary web-based environments because tools such as Desmos extend graphing functionality by making dynamic visualization easily available through computers and mobile devices. More recent higher-education research has also examined Desmos in relation to mathematical communication and independent learning in calculus. Students using dynamic graphing environments can represent concepts visually, compare alternative solutions, and verify mathematical ideas, which may support greater independence during problem solving [10].

Thus, the reviewed literature suggests that GeoGebra and Desmos can contribute to mathematical learning through three interconnected mechanisms: dynamic visualization, active experimentation, and immediate feedback. Nevertheless, technology itself is not a pedagogical method. Its educational value depends on the quality of the mathematical tasks and the extent to which students are required to predict, explain, compare, justify, and reflect on their findings.

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METHODOLOGY

A mixed-method pedagogical research design can be employed to investigate the influence of GeoGebra and Desmos on students' mathematical competence. A quasi-experimental approach is appropriate because it enables comparison between students studying through technology-enhanced activities and those receiving predominantly conventional instruction. For example, a study may involve 60 undergraduate students enrolled in a mathematics-related course. The participants can be divided into an experimental group (n = 30) and a comparison group (n = 30). Both groups study the same mathematical topics and receive an equal amount of instructional time. The principal difference is the learning environment. The experimental group completes selected mathematical activities through GeoGebra and Desmos. These activities may include graph transformation, function analysis, geometry, systems of equations, and elementary calculus. The comparison group studies equivalent content through teacher explanation, textbooks, static diagrams, and conventional problem-solving exercises. Four instruments can be used to collect data: a mathematical competence pre-test and post-test, an observation checklist, a student questionnaire, and short reflective responses. The mathematical test should assess not only calculation but also conceptual understanding, problem-solving, interpretation of graphical information, and mathematical reasoning.

For example, students may first be given the function

[
f(x)=x^2.
]

They are then asked to predict the effects of changing it to

[
g(x)=a(x-h)^2+k.
]

Before manipulating the graph, students record their predictions. They subsequently use GeoGebra or Desmos sliders to modify (a), (h), and (k), observe the resulting transformations, and explain whether their initial predictions were correct. This predict–explore–explain sequence allows the software to function as a cognitive tool rather than merely as a graph generator. Quantitative data can be analyzed by comparing pre-test and post-test results and calculating mean improvement. Questionnaire responses can be summarized using percentages or Likert-scale means. Qualitative responses can be analyzed thematically according to categories such as visualization, motivation, confidence, mathematical reasoning, independent exploration, and perceived difficulty.

ANALYSIS AND RESULTS

The pedagogical analysis suggests that interactive mathematical environments can affect mathematical competence at several levels. First, visualization enables students to establish stronger connections between symbolic expressions and graphical representations. A learner who sees (y=x^2) only as an algebraic formula may have difficulty predicting how (y=(x-3)^2+2) changes the graph. Through dynamic manipulation, the student can immediately observe a translation three units to the right and two units upward. Second, interactive environments support exploratory learning. Students can formulate hypotheses and test them without repeatedly drawing a completely new graph. For example, while studying the equation

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[
y=ax+b,
]
students may manipulate (a) and discover that increasing its absolute value changes the steepness of the line, while changing (b) moves the line vertically. The important pedagogical stage occurs when students are subsequently required to explain these observations using mathematical language.

Third, the psychological analysis indicates several possible mechanisms of influence. Immediate visual feedback can strengthen students' sense of control over the learning process. The opportunity to correct a mathematical construction without public failure may also encourage experimentation. However, digital activity should not be interpreted automatically as cognitive engagement. A student may move sliders repeatedly without understanding the mathematical relationship. Teacher questions such as *"What did you predict?", "Why did this change occur?"* and *"Can you express the pattern algebraically?"* are therefore essential.

The following table demonstrates how results from a hypothetical sample could be organized. The values are illustrative and should be replaced by empirical results after an actual experiment.

Table 1.

Illustrative model for comparing mathematical competence before and after technology-enhanced instruction[1]

Indicator	Experimental Group: Pre-test	Experimental Group: Post-test	Comparison Group: Pre-test	Comparison Group: Post-test
Conceptual understanding	61%	84%	60%	71%
Problem-solving competence	58%	81%	59%	69%
Graphical interpretation	56%	86%	57%	68%
Mathematical reasoning	60%	82%	61%	72%
Overall mathematical competence	59%	83%	59%	70%

In this illustrative model, the experimental group demonstrates a 24-percentage-point increase in overall mathematical competence, compared with an 11-point increase in the comparison group.

[1] The numerical values presented in the table are illustrative rather than empirical data taken directly from the cited study. Juandi et al. [5] analyzed 36 effect sizes from 29 primary studies involving 2,111 students and reported an overall positive effect of GeoGebra-supported instruction on students' mathematical abilities.

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These figures should **not** be reported as actual findings unless they are obtained from empirical data. They show how the results of a real classroom experiment may later be presented and interpreted. The pattern is consistent with previous research reporting positive associations between GeoGebra-supported learning and mathematical achievement [5] and with studies demonstrating the usefulness of Desmos-supported visualization in algebra learning [7]. At the same time, the pedagogical interpretation is more important than a simple comparison of scores. Interactive tools appear most educationally valuable when visualization is combined with prediction, reasoning, discussion, and explanation.

From the psychological perspective, the expected changes include greater willingness to participate, increased curiosity, reduced dependence on the teacher for immediate verification, and greater confidence in experimenting with mathematical ideas. For example, instead of asking the teacher whether a graph is correct, a student can test the equation dynamically and compare different representations. This provides immediate feedback while preserving the teacher's role in guiding conceptual interpretation.

Therefore, GeoGebra and Desmos should not be viewed simply as technological additions to mathematics lessons. Their educational significance lies in creating an interactive space in which mathematical objects can be manipulated, hypotheses can be tested, and abstract relationships can become observable. When supported by carefully designed pedagogical tasks, such an environment has the potential to strengthen mathematical competence while simultaneously encouraging motivation, autonomy, and active cognitive participation.

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