

Improving the Teaching of “Mathematical Modeling” in a Digital Learning Environment: An Innovative Path for Educational Development

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ABSTRACT

Objective: This study examines the theoretical foundations, methodological model, and experimental results of improving the teaching methodology of the “Mathematical Modeling” course in a digital learning environment. Its objective is to substantiate a digital methodological system that moves students from reproductive activity based on applying ready-made formulas to independent activity involving the analysis of real processes, construction of mathematical models, interpretation of computational results, and verification of their reliability. **Method:** The study used analysis of scientific and pedagogical literature, pedagogical observation, diagnostic testing, practical assignments, digital learning analytics, comparative analysis, and experimental methods. The experiment was conducted from 2022 to 2025 at three higher education institutions and involved 480 students. It employed 15 learning management system-based modules, interactive computational tools, entry and exit diagnostics, independent learning blocks, and criterion-referenced assessment. **Results:** The findings showed an average 10.7% increase in learning achievement in the experimental groups. Students also became more active in explaining the assumptions, limitations, and practical meaning of a model. **Novelty:** The scientific novelty of the study lies in integrating digital tools, the modeling cycle, feedback, and assessment into a unified didactic system that supports independent learning, professional thinking, and evidence-based decision-making.

INTRODUCTION

Today, the digital transformation of education is not limited to converting textbooks into electronic form or using computers in the classroom. A digital environment constitutes a new didactic space that affects the pace at which students learn, the way they complete assignments, how they analyze errors, and how they evaluate their own results. The Digital Uzbekistan – 2030 Strategy also identifies the digitalization of education, alongside the economy and social sectors, as a priority [1]. Therefore, the introduction of digital tools in higher education should be understood not merely as technical modernization but as a methodological process requiring a reconsideration of instructional goals, content, and outcomes [2].

The course “Mathematical Modeling” is particularly important in this context. It requires students to observe a real object or phenomenon, identify the essential factors, formulate simplifying assumptions, establish mathematical relationships, obtain a solution, and compare the result with the original real-world conditions. M. Niss and W. Blum describe mathematical modeling not as a single transition between a real situation and mathematics, but as a cyclical activity in which the stages of understanding, mathematizing, solving, interpreting, and validating are repeated [3]. Consequently,

teaching the course solely through formulas and ready-made algorithms cannot fully reveal its essential nature [4].

In conventional classes, students often solve a model selected by the teacher, while the reasons for selecting that model, the effect of the adopted assumptions on the result, and the limits of its application are not analyzed sufficiently. When assignments are offered at a single level of difficulty, students with different levels of prior preparation are compelled to work at the same pace. Delayed feedback may also reinforce an incorrect mode of reasoning. For this reason, the research problem was defined by the need to align the capabilities of digital tools with the staged logic of modeling and to develop students' independent decision-making and conscious use of models in professional situations [5].

The scientific novelty of the study consists in organizing the 15 topics of the “Mathematical Modeling” course into digital modules based on diagnosis, problem situations, model construction, computational experimentation, interpretation, reflection, and criterion-referenced assessment. Its practical significance is determined by the possibility of using the developed modules, interactive tools, and assessment map in face-to-face, blended, and independent learning in higher education.

RESEARCH METHOD

The conceptual idea underlying the improved methodology is to use the digital platform not as an auxiliary technical tool added to the lesson, but as a didactic system that consistently organizes the activities of the teacher and the student. Within this system, learning objectives, theoretical concepts, real-world problems, model construction, computational experimentation, interpretation of results, feedback, and assessment are interconnected. In this approach, every video, interactive calculator, test, or consultation window serves a specific cognitive operation performed by the student. In the DigCompEdu framework developed by C. Redecker, an educator's digital competence is likewise defined not merely by the ability to use devices, but by the capacity to select digital resources, design instruction, conduct assessment, and make the learner an active participant.

In the author's methodology, the 15 topics of the “Mathematical Modeling” course were divided into digital learning modules. Each module begins with an entry task designed to determine the student's initial level of preparation. This is followed by a concise theoretical explanation, worked examples, a computational tool that allows parameters to be varied, a practical situation, an independent assignment, and an exit assessment. This structure helps students move from the pattern of “listen first and then repeat” to the activity of “identify the problem, formulate a hypothesis, test it, correct errors, and draw a conclusion.” The digital tutoring assistant does not provide a ready-made answer; instead, it asks guiding questions that help students divide the problem into smaller stages, identify variables, or verify the result.

The process of constructing a mathematical model was organized in the learning activities as a consistent cycle. First, the meaning of the real-world situation is examined,

and the objective and problem are formulated precisely. At the next stage, the essential variables, parameters, and constraints are selected, while secondary factors are simplified on a reasoned basis. The relationships among them are then expressed as an equation, a system of equations, a function, an algorithm, or a statistical model. After the model is solved analytically or numerically, the result is transferred back to the real process and checked for logical consistency. When the result does not correspond to observations or the stated conditions, the student revises the model, parameter values, or initial assumptions. M. Blomhøj and T. Højgaard Jensen have shown that mathematical modeling competence is formed through carrying out the complete process and developing its individual subcompetencies in a balanced manner.

One of the important advantages of a digital environment is the ability to change model parameters rapidly and observe the resulting differences. For example, when a student modifies an initial condition, coefficient, or boundary value, changes in the graph and table can be observed immediately. Such a computational experiment raises questions that are deeper than the simple search for a “correct answer”: Which parameter had the strongest effect on the result? Is the model stable? Does the obtained value have a physical or economic meaning? Can the result be verified using another method? R. Mayer’s research on multimedia learning also demonstrates that learning material is understood more deeply when text, images, and graphs are combined purposefully, whereas excessive decoration and irrelevant information increase cognitive load. Therefore, visual elements in the developed modules were used not for decoration, but to explain the structure of the model and its results.

Assessment was not limited to recording the final answer; it was directed toward diagnosing every stage of the modeling process. The student’s understanding of the problem, selection of variables and parameters, justification of assumptions, construction of the mathematical expression, performance of computations, interpretation of results, and defense of the conclusion were evaluated using separate criteria. The aggregate score was expressed as $B = R_1 + R_2$, where R_1 represents the results of current and practical activities across the topics, while R_2 represents the result of the final modeling assignment. Each topic was assessed on a 100-point scale, producing a 1,500-point diagnostic map across 15 topics. In addition to the total score, this map enabled the teacher to identify the specific stage at which a student encountered difficulty.

RESULTS AND DISCUSSION

The experimental work was conducted from 2022 to 2025 with 155 students at Bukhara State University, 173 students at the Jizzakh Branch of the National University of Uzbekistan, and 152 students at Karshi State University. In total, the learning outcomes, assignment-completion processes, and reflective responses of 480 students were analyzed comparatively [6]. The experimental groups used digital modules, interactive computational tools, staged feedback, and criterion-referenced assessment, while the existing instructional procedure was retained in the control groups. Entry and exit diagnostics were administered using identical content-based criteria [7].

The final analysis showed that learning achievement increased by an average of 10.7% in the groups where the improved methodology was applied [7]. The quantitative results were also supported by qualitative changes in students’ thinking. At the beginning, some students regarded a model as a ready-made formula; by the end of the experiment, they were able to explain it as a simplified representation of a real object constructed for a specific purpose [8]. Rather than limiting themselves to the question “What is the answer?”, students increasingly asked analytical questions such as “Why was this particular model selected?”, “Which change in the conditions would alter the result?”, and “How can the result be verified?” This indicates that mathematical modeling had developed from a computational skill into a tool of professional thinking [9].

The results showed that a digital learning environment does not reduce the role of the teacher; on the contrary, it expands the teacher’s methodological responsibility. The teacher is no longer limited to transmitting information, but acts as a specialist who selects problem situations, designs learning pathways, analyzes errors, provides guidance, and interprets educational data pedagogically [10]. Platform statistics can show which assignment produced the greatest number of errors, but the teacher must determine whether the cause is a misconception, reduced motivation, or interface complexity. Therefore, meaningful communication, impartial assessment, academic integrity, and respect for the learner remain fundamental principles in the digitalization process [11].

Several limitations were considered when interpreting the research results. Because the experiment was conducted at three higher education institutions and within a single course, direct generalization of the findings to other disciplines and educational programs requires caution. In addition, factors such as students’ initial preparation, prior experience with digital platforms, and internet quality may influence learning outcomes [12]. These factors were controlled through entry diagnostics, uniform assessment criteria, and platform analytics. Future research should examine the long-term effects of the methodology, its effectiveness across different disciplines, and the influence of the digital assistant on individualized learning trajectories [13].

In higher education institutions, implementation of this methodology should begin not with the selection of a platform, but with the definition of expected learning outcomes. At the end of each module, it is necessary to specify not only what the student should know, but also which activity the student should be able to perform independently. A real-world assignment, the stages of model construction, rapid feedback, assessment criteria, and reflection questions are then developed. A digital tool is selected according to the functions that facilitate this process [14]. The platform’s ability to operate with low-speed internet, compatibility with mobile devices, simplicity of the interface, and protection of learning data are also necessary conditions for methodological effectiveness.

The proposed methodology is not limited to the “Mathematical Modeling” course. Its logic, consisting of diagnosis, a problem-based assignment, computational

experimentation, feedback, reflection, and criterion-referenced assessment, can be adapted to computer science, applied mathematics, physics, economics, and engineering disciplines. The subject content and tools will change, but the learner’s pathway from a real problem to a scientifically grounded solution will remain. The European Commission’s Digital Education Action Plan likewise identifies the creation of a high-quality, inclusive, and accessible digital education ecosystem as a priority [15].

CONCLUSION

Fundamental Finding : Effective teaching of the “Mathematical Modeling” course in a digital learning environment is achieved not by increasing the number of technical tools, but by subordinating them to clearly defined didactic purposes. The principal outcome is the student’s ability to analyze a real problem, construct a model independently, interpret the computational result, and verify its reliability. The developed methodology organized the learning content into 15 digital modules and integrated entry and exit diagnostics, interactive computational experimentation, independent assignments, staged feedback, and criterion-referenced assessment into a unified system. The experiment conducted with 480 students at three higher education institutions confirmed the practical effectiveness of the methodology. Learning achievement in the experimental groups increased by an average of 10.7%, and students paid greater attention to explaining the meaning, limitations, and results of a model rather than merely applying a ready-made formula. This finding demonstrates that, when designed with pedagogical consistency, a digital environment develops independent learning, professional thinking, and evidence-based decision-making competencies. **Implication :** The value of scientific and pedagogical activity is determined by the practical results produced by an idea. A student’s ability to divide a complex problem into stages, identify an error, explain the capabilities and limitations of a model, and reach a scientifically grounded conclusion is an important outcome of a teacher’s work. Directing the digital learning environment toward human interests, the quality of knowledge, and future professional activity remains one of the priorities of contemporary pedagogy. **Limitation :** This study involved only 480 students from three higher education institutions and did not examine the long-term sustainability of the learning outcomes. Differences in students’ digital competence, mathematical ability, and access to technology were also not analyzed. **Future Research :** Future research should involve more diverse institutions, use longitudinal designs, and compare digital, blended, and conventional learning. Further studies may also examine the role of digital literacy, teacher competence, and artificial intelligence in mathematical modeling instruction.

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