

# PEDAGOGY AND DIDACTICS IN INFORMATIZATION ПЕДАГОГИКА И ДИДАКТИКА ИНФОРМАТИЗАЦИИ

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## Methodological aspects of implementing computer modeling in teaching higher mathematics in the mathematical training of students

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**Abstract.** *Problem statement.* The addresses the methodological problem of integrating computer modeling into the teaching of higher mathematics to improve the mathematical training of university students. Modern educational practice shows that traditional methods do not always provide sufficient clarity and visualization when studying complex mathematical concepts. *Methodology.* The study is based on analyzing the effectiveness of using the Maple computer system during lectures, practical sessions, and independent work. The approach includes evaluating learning outcomes, examining students' engagement, and assessing the impact of computational visualization on the understanding of mathematical material. *Results.* This the systematic use of Maple significantly enhances the assimilation of theoretical concepts, supports the development of analytical thinking, and increases students' performance in higher mathematics is demonstrate. The integration of computer modeling proved especially effective in topics requiring symbolic computation, visualization, and multi-step problem solving. *Conclusion.* The conclusion highlights that the incorporation of computer modeling into mathematical training provides a more practice-oriented, accessible, and efficient learning environment. The findings confirm the importance of using Maple as a pedagogical tool to strengthen students' mathematical competence and improve the overall quality of mathematical education.

**Keywords:** Maple computer system, computational tools, visualization, educational technology, engineering education, learning outcomes

**Conflict of interest.** The author declares that there is no conflict of interest.

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## Методологические аспекты внедрения компьютерного моделирования в преподавание высшей математики в процессе математической подготовки студентов

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**Аннотация.** *Постановка проблемы.* Рассматривается методологическая проблема интеграции компьютерного моделирования в процесс преподавания высшей математики с целью повышения качества математической подготовки студентов университетов. Современная образовательная практика показывает, что традиционные методы не всегда обеспечивают необходимую степень наглядности и визуализации при изучении сложных математических концепций. *Методология.* Исследование основано на анализе эффективности использования компьютерной системы Maple в ходе лекций, практических занятий и самостоятельной работы студентов. Подход включает оценку учебных результатов, анализ вовлеченности обучающихся и изучение влияния визуализации вычислений на понимание математического материала. *Результаты.* Демонстрируется, что систематическое применение системы Maple значительно повышает усвоение теоретических понятий, способствует развитию аналитического мышления и приводит к росту успеваемости студентов по высшей математике. Интеграция компьютерного моделирования оказалась особенно эффективной в темах, требующих символических вычислений, визуализации и решения многоэтапных задач. *Заключение.* Подчеркивается, что включение компьютерного моделирования в математическую подготовку в большей степени обеспечивает практико-ориентированную, доступную и эффективную образовательную среду. Полученные выводы подтверждают важность использования Maple как педагогического инструмента для укрепления математической компетентности студентов и повышения общего качества математического образования.

**Ключевые слова:** компьютерная система Maple, вычислительные инструменты, визуализация, образовательные технологии, инженерное образование, учебные результаты

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**Problem statement.** In modern scientific and educational practice, the study of higher mathematics plays a central role in the development of professional competence among students of technical specialties. As many researchers note, the rapid advancement of computational technologies has fundamentally transformed approaches to mathematical analysis and problem solving in science and engineering. The increasing complexity of applied tasks requires not only strong theoretical knowledge but also the ability to employ advanced digital tools capable of supporting symbolic computation, numerical experimentation, and visual representation of mathematical structures [1].

Traditional methods of teaching mathematics, while foundational, often fail to provide the level of clarity and interactivity needed for deep comprehension of abstract concepts. Numerous studies emphasize that manual calculations and classical demonstration formats limit students' ability to fully grasp multidimensional models, dynamic processes, and complex transformations that are characteristic of modern scientific investigations. According to scholars working in the field of mathematical education, this gap between theoretical instruction and real-world applications underscores the necessity of revising methodological approaches in technical universities [2; 3].

The emergence and development of computer mathematics as an independent scientific direction significantly contributed to this shift. Works by Dyakonov, Melnikov and others demonstrate that mathematical modeling has become a universal tool for describing physical, technical, and economic phenomena, allowing researchers to convert real-world problems into formalized analytical structures suitable for computational study. The integration of modeling techniques into mathematics education therefore becomes a logical and necessary step, enabling students to better understand the internal logic of mathematical objects and to explore their behavior under varying conditions.

Within this context, special attention is given to computer algebra systems, which provide extensive capabilities for symbolic transformations, graphical interpretation, and the automation of complex calculations. Among them, the Maple system occupies a prominent place due to its versatility and wide adoption in higher education and scientific research. As highlighted in the works of Rakhimov, Ignatiev, and other specialists, Maple allows for the effective combination of traditional mathematical theory with interactive modeling tools, supporting both analytical reasoning and computational experimentation.

Despite these advantages, the problem of developing a clear and structured methodology for implementing computer modeling into the teaching of higher mathematics remains highly relevant. Researchers in Tajikistan, Russia and other countries note that the potential of such systems is not fully utilized due to methodological gaps, insufficient integration into curricula, and the lack of unified approaches to combining classical and digital methods of instruction. At the same time, empirical evidence shows that when modeling tools are systematically

introduced into lectures, practical classes, and independent work, students demonstrate higher learning outcomes, deeper conceptual understanding, and stronger motivation to engage with mathematical content [4].

Thus, the central *problem* addressed in this article concerns the methodological foundations and practical aspects of integrating computer modeling – particularly the Maple system – into the mathematical preparation of students in technical universities. The key challenge lies in defining effective pedagogical strategies that enhance the visibility, accessibility, and applicability of mathematical knowledge while maintaining the rigor of traditional academic training. The search for such strategies necessitates detailed theoretical analysis, evaluation of current teaching practices, and consideration of the specific needs of students mastering higher mathematics in the context of rapidly evolving computational technologies.

**Methodology.** The methodological foundations of integrating computer modeling into the teaching of higher mathematics are rooted in the rapid development of computational technologies and their growing influence on modern scientific practice. As noted by numerous researchers in the field of mathematics education across Russia and Central Asia, the increasing complexity of scientific and engineering tasks requires new approaches to structuring mathematical training in technical universities. Classical methods based exclusively on theoretical exposition and manual calculations often prove insufficient for developing the type of analytical and applied competencies that contemporary students must acquire. This situation has generated a sustained interest in tools that support visualization, symbolic manipulation, and the modeling of mathematical structures, which form the basis of many scientific and engineering disciplines.

The evolution of computer mathematics as an independent scientific direction has played a crucial role in shaping new methodological approaches to teaching higher mathematics. Foundational works in this area emphasize that computer mathematics allows a transition from static, purely symbolic forms of representation to dynamic, interactive environments that reflect the internal logic of mathematical objects more effectively than traditional forms of instruction. According to established interpretations presented in the scientific literature, mathematical modeling has become an essential framework for understanding and analyzing complex systems, enabling the abstraction of real-world processes into formal structures suitable for computational experimentation. This shift has broadened the conceptual and methodological toolkit available to educators, allowing them to more effectively convey essential mathematical ideas.

Recent studies by researchers from technical universities in the region highlight the growing importance of integrating computational tools into the educational process. They argue that the ability to systematically analyze algebraic expressions, functions, sequences, and other mathematical constructs through modeling contributes to a deeper and more intuitive understanding of theoretical material. Moreover, computational systems allow the demonstration of properties and

structures that are inaccessible through traditional chalkboard explanations. This methodological enrichment enables students to approach mathematical problems from multiple perspectives, enhancing both the learning process and the quality of the resulting knowledge.

Within this broader scientific and pedagogical context, particular attention is paid to computer algebra systems that provide extensive capabilities for symbolic and numerical computation. A number of authors emphasize that such systems offer unique opportunities for bridging the gap between abstract mathematical theory and its practical applications. The Maple system, in particular, has attracted significant attention due to its combination of symbolic computation, numerical methods, and powerful visualization tools. The literature [5] reflects a consistent view that Maple supports not only the execution of routine mathematical operations, but also the exploration of complex structures and relationships that are central to higher mathematics. Through these capabilities, students can observe transformations, evaluate expressions under changing parameters, and interact with mathematical constructs in ways that promote deeper conceptual understanding.

**Results and discussion.** The methodological rationale for using Maple in the teaching of higher mathematics is based on several key principles identified in the educational research of the region. First, computer modeling enables the creation of dynamic visual representations that reveal hidden properties of mathematical objects. This visual dimension enhances the interpretability of theoretical concepts and allows students to recognize connections that may not be apparent through traditional methods. Second, the use of computational tools reduces the cognitive load associated with performing repetitive or technically demanding calculations. As a result, students are able to focus more fully on understanding underlying principles rather than on manual computational mechanics. Finally, the introduction of a computer algebra system encourages independent exploration and experimentation, fostering the development of analytical thinking and problem-solving skills that are essential for future engineers and specialists [6].

The methodological literature further underscores the importance of aligning computational tools with traditional mathematical training. The use of Maple should not replace classical methods, but rather complement them by providing additional layers of clarity and accessibility. Educators must therefore consider how to integrate computer modeling in a way that preserves mathematical rigor while enhancing the learning process. This includes identifying topics for which computational visualization is particularly beneficial, selecting appropriate tools within the system, and ensuring that students understand both the computational and theoretical aspects of the material. Such an approach reflects the perspectives of researchers who advocate for a balanced, pedagogically informed integration of digital tools into mathematical instruction.

A significant aspect of this methodology concerns the gradual introduction of modeling tools to support the study of increasingly complex mathematical topics. In the early stages, students may engage with simple symbolic transformations and

basic visualizations that illustrate fundamental properties of functions, sequences, or algebraic expressions. As their familiarity with computational tools grows, they can progress toward more sophisticated forms of modeling that reflect higher-level mathematical reasoning. This structured progression corresponds to the recommendations found in contemporary educational studies, which emphasize the importance of scaffolding students' engagement with computational systems to ensure meaningful and sustained learning outcomes.

Of particular importance within this methodological framework is the role of computer modeling in combinatorics and probability theory, areas of mathematics that rely heavily on structural patterns, systematic enumeration, and quantitative reasoning. Researchers highlight that traditional instruction may fail to fully convey the breadth and depth of combinatorial constructs when relying solely on symbolic notation and manual calculation. Computer modeling offers an effective means of addressing these limitations by enabling students to visualize combinatorial structures, examine the effects of parameter changes, and experiment with probabilistic models in a controlled environment. In this context, Maple becomes a powerful tool for reinforcing theoretical knowledge and providing insight into the behavior of discrete systems.

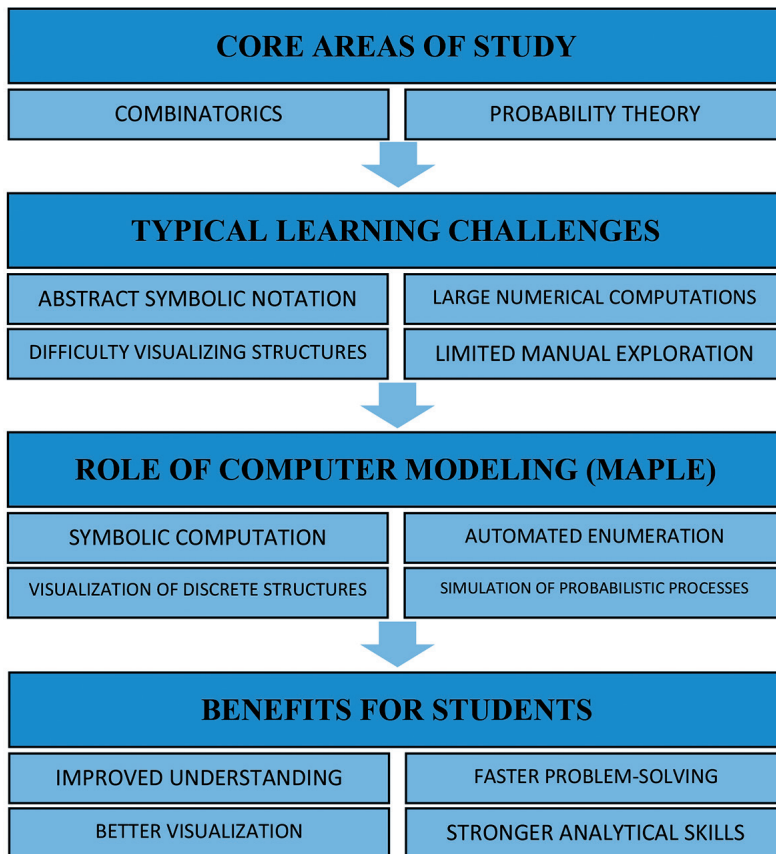
Finally, the methodological principles discussed above create the foundation for a practice-oriented approach to teaching higher mathematics through computer modeling. By combining classical mathematical instruction with dynamic computational tools, educators can create a learning environment that not only supports the understanding of abstract concepts, but also prepares students to apply these concepts in real-world contexts. This integration reflects broader trends in technical education and responds to the evolving demands of scientific and industrial fields. The theoretical considerations presented in this section form the basis for the practical implementation of computer modeling, which is examined in the subsequent part of the methodology.

The practical implementation of computer modeling within the mathematical training of students requires a structured and conceptually coherent approach that integrates computational tools into the study of key theoretical topics. In this regard, the Maple computer algebra system plays a central methodological role, as it offers a rich set of instruments for symbolic transformations, numerical analysis, and the visualization of mathematical structures. The practical dimension of this methodology is based on the premise that computational modeling does not replace traditional mathematical instruction, but significantly enhances it by providing students with a dynamic and interactive medium for exploring theoretical material. This dual reliance on classical mathematical reasoning and advanced computational capabilities forms the core of contemporary approaches to teaching higher mathematics in technical universities.

In the context of implementing modeling techniques, combinatorics and probability theory represent subject areas in which the benefits of computational tools are particularly evident. These fields require systematic enumeration, analysis

of structural dependencies, and exploration of parameter-driven outcomes, tasks that often exceed the limits of manual calculation, especially when large numerical values or multidimensional structures are involved. Computer modeling allows students to engage with complex combinatorial objects, examine their internal symmetries, and analyze probabilistic patterns that emerge from discrete processes. By automating routine computations, Maple enables learners to focus on conceptual relationships, thereby deepening their understanding of the underlying mathematical foundations [7].

A key methodological component involves introducing students to combinatorial reasoning through computational experiments that reflect theoretical principles. Such an approach allows learners to observe the behavior of combinatorial constructs in real time and experiment with varying parameters. For example, problems related to permutations, combinations, and arrangements provide a natural entry point for examining the structure of discrete sets and illustrating foundational ideas in probability theory. Maple’s ability to compute large factorial expressions, generate subsets of different sizes, and visualize combinatorial relationships makes it a particularly effective tool for this purpose (Figure 1).

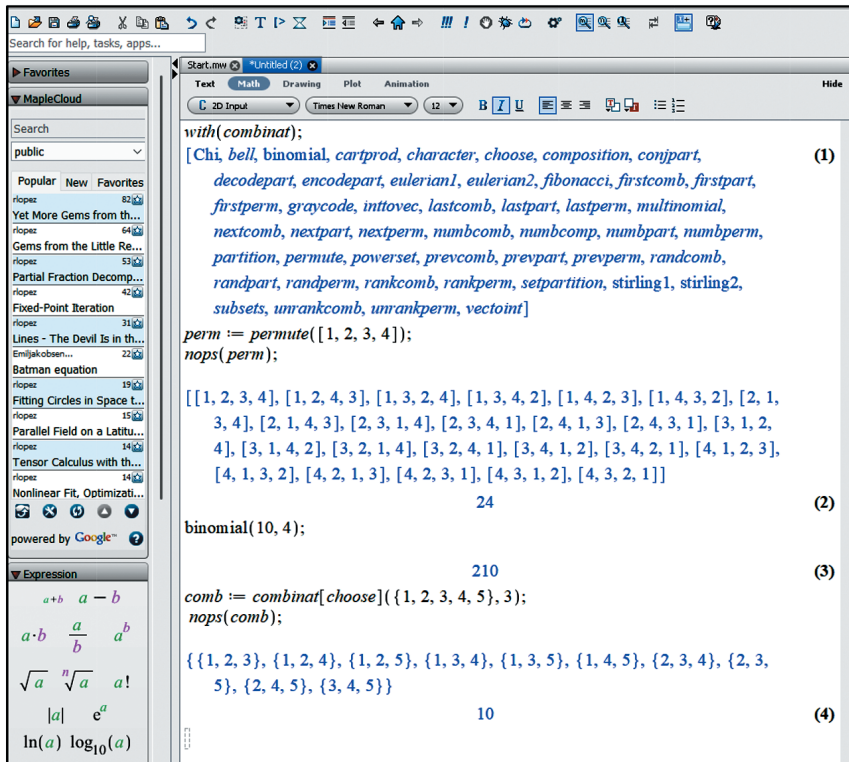


**Figure 1.** Conceptual diagram of the role of computer modeling in the study of combinatorics and probability

Source: created by Amon A. Rakhimov.

The use of computer modeling extends beyond the computation of numerical values; it offers opportunities for constructing graphical and schematic representations of discrete processes. When students work with probability trees, enumerations of outcomes, or combinatorial structures such as Pascal’s triangle, Maple provides a platform for generating visual models that enhance interpretability and facilitate more meaningful engagement with the theoretical material. Such visualizations allow students to recognize recurring patterns, dependencies, and structural characteristics that define the behavior of discrete mathematical objects. These insights play a significant role in developing higher-order thinking skills and analytical abilities.

From a methodological standpoint, computational modeling encourages students to develop independent problem-solving strategies. When working with tasks involving the enumeration of outcomes or the calculation of probabilities, learners must identify the appropriate combinatorial framework before using Maple to validate and expand their reasoning. This interplay between conceptual understanding and computational experimentation forms an important pedagogical mechanism for reinforcing theoretical knowledge. For instance, problems involving the calculation of binomial coefficients, probabilities of compound events, or analysis of random selections can be modeled in Maple to produce both numerical results and corresponding visual representations (Figure 2).



**Figure 2.** Example of Maple output showing combinatorial calculations such as permutations, combinations, or binomial coefficients

Source: created by Amon A. Rakhimov based on data from V.E. Gruman [8].

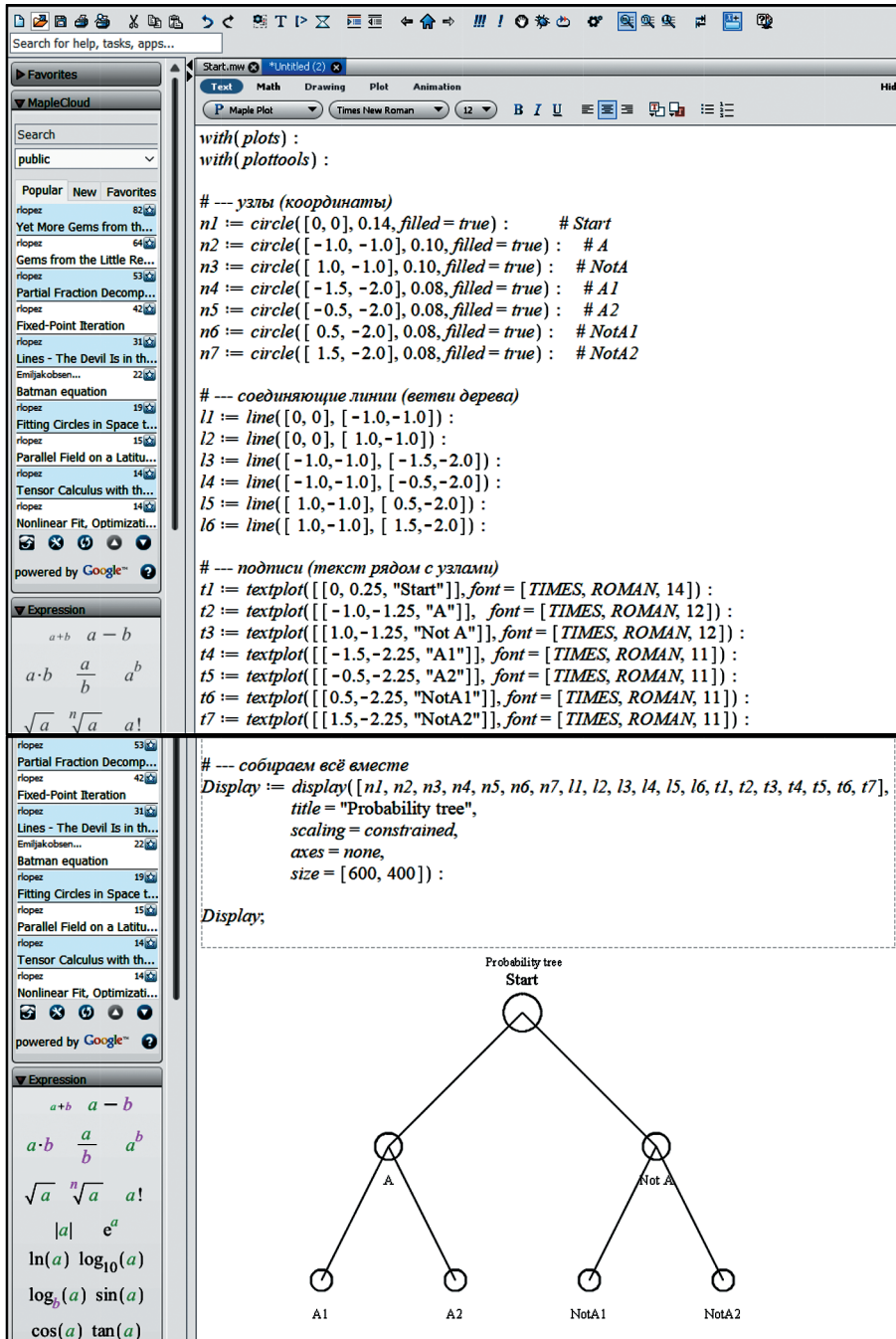
In problems where the structure of the sample space is central to understanding probabilistic outcomes, Maple allows for the generation of explicit lists of possible events. This function is particularly useful in exploring tasks related to random selections, arrangements, and partitioning of sets. Students can examine the complete set of outcomes, analyze the effects of constraints on the solution space, and observe how variations in parameters influence the probabilities of different events. Such modeling exercises not only support conceptual clarity but also promote the acquisition of practical skills in handling discrete data structures [9].

Moreover, the capabilities of Maple facilitate a deeper examination of probabilistic distributions and their applications in engineering and scientific contexts. For example, students can simulate random processes, examine the frequencies of outcomes, and compare empirical results with theoretical expectations. This type of computational modeling helps bridge the gap between abstract probabilistic concepts and real-world phenomena. By analyzing patterns that emerge from repeated simulations, learners gain insight into fundamental ideas such as the law of large numbers, variance, and distributional behavior. These experiences foster a more holistic understanding of probability theory and prepare students for advanced applications in their respective fields.

An important methodological aspect of practical modeling is the structured integration of computational tools into specific stages of mathematical instruction. Although the approach does not rely on formal distinctions between lectures and practical classes, it follows a logical progression that moves from conceptual exposition to computational representation and finally to analytical interpretation. Students first encounter theoretical principles through exposition and discussion, after which they transition to computational exploration using Maple. Through this integration, computational tools become an extension of theoretical understanding rather than an isolated technological addition.

To further support the development of student competencies, the methodology includes targeted tasks that require the application of Maple to solve increasingly complex problems. For instance, learners may model multi-stage probabilistic processes, analyze combinations with constraints, or examine conditional probabilities through computational experimentation. In each case, Maple serves as an environment in which students can test hypotheses, explore alternative solutions, and evaluate the effects of different assumptions [10]. This form of inquiry-driven learning reflects the broader goals of higher mathematical education, which emphasize the development of critical thinking and analytical precision (Figure 3).

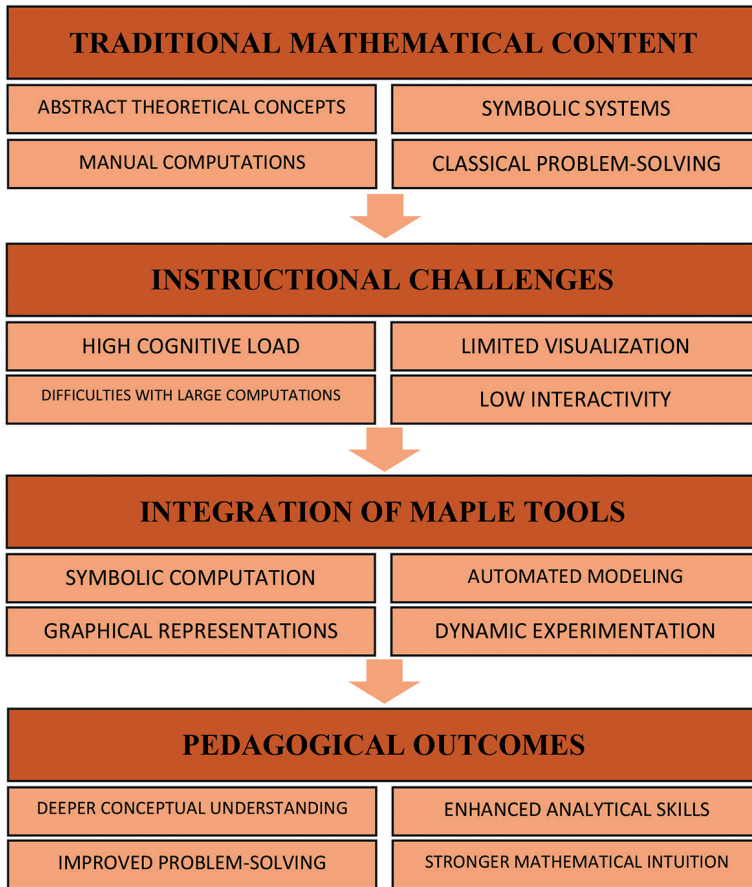
Additionally, the use of computational modeling supports the gradual development of students' ability to work with mathematical abstractions. As learners interact with computational representations of mathematical objects, they gain experience in interpreting symbolic expressions, analyzing structural properties, and relating theoretical principles to computational outputs. These skills are essential for advanced studies in mathematics, engineering, and computer science. The pedagogical literature consistently emphasizes that such activities contribute to the formation of cognitive flexibility and the ability to transfer mathematical knowledge across different contexts [11].



**Figure 3.** Illustration of a probability tree (or combinatorial structure) generated in Maple  
 Source: created by Amon A. Rakhimov based on data from V.E. Gruman [8].

The methodological framework outlined here also aligns with research indicating that student engagement increases when abstract mathematical ideas are supported by computational visualization. Maple’s graphical capabilities enable the creation of plots, diagrams, and schematic representations that complement symbolic derivations and enhance conceptual clarity [12]. This dual-mode learning – combining symbolic reasoning with computational visuals – has

been shown to be particularly effective in helping students internalize complex ideas and develop the ability to manipulate mathematical structures confidently (Figure 4).



**Figure 4.** Schematic representation of the integration of Maple into the methodological framework of teaching higher mathematics

Source: created by Amon A. Rakhimov.

Finally, the practical component of the methodology establishes the foundation for evaluating the overall effectiveness of integrating computer modeling into mathematical education. While the present work does not include an experimental analysis of student performance, the methodological principles developed here demonstrate how computational tools can be systematically incorporated into the study of higher mathematics in a way that strengthens theoretical understanding, enhances analytical skills, and prepares students for future professional activities. By emphasizing the role of modeling in combinatorics and probability – areas that are central to many technical disciplines – the methodology ensures that students gain experience in using computational tools to explore, represent, and analyze mathematical structures [13; 14]. These elements form a coherent foundation for the subsequent conclusions of the study and underscore the pedagogical significance of integrating computer modeling into higher mathematics.

*Approbation and implementation of the research results.* The practical approbation of the developed methodology was carried out at the Polytechnic Institute of the Tajik Technical University named after Academician M.S. Osimi. The proposed approaches to the integration of computer modeling into the higher mathematics course were implemented in the educational process of students of the study program 40.01.01 “Software of Information Technologies and Automated Systems”. During the experimental training, students used the Maple system to model discrete structures, visualize functions, and verify algorithms for solving probability problems. The results of the implementation demonstrated that the use of high-level computational tools enables future programmers to more quickly master the transition from mathematical abstraction to program implementation. Teaching experience also confirmed an increase in student engagement and an improvement in the quality of independent work requiring complex analysis and multi-stage computations.

*The results of the approbation demonstrate the following:*

1. Increase in the level of abstract thinking – Students became more successful in transitioning from problem formulation to its formalized description, using Maple as an intermediate link between mathematical theory and program code.

2. Improvement in the quality of learning – The use of visualization in Maple made it possible to reduce the time required to study topics with complex geometric and probabilistic interpretations (multidimensional distributions, combinatorial structures).

3. Development of professional competencies – The approbation confirmed that working with a computer algebra system directly prepares students for the design of automated systems, as it teaches them to verify computational results and analyze model errors.

4. Growth of cognitive activity – A significant increase in interest in independent research activities was observed, as Maple computational tools reduce the “complexity barrier” when solving problems involving large volumes of data [15; 16].

**Conclusion.** The integration of computer modeling into the teaching of higher mathematics represents an essential methodological direction for improving the quality of mathematical training in technical universities. The theoretical and practical considerations examined in this article demonstrate that computational tools such as the Maple system significantly expand the instructional capabilities available to educators and contribute to a more profound understanding of abstract mathematical concepts. By complementing traditional forms of mathematical instruction, computer modeling enhances the clarity, accessibility, and structural coherence of the learning process, particularly in areas that require systematic enumeration, symbolic transformations, and the analysis of discrete systems.

The methodological framework developed in this study underscores the importance of aligning computational modeling with classical mathematical reasoning. Maple’s capabilities for symbolic computation, numerical experimentation, and visual representation create conditions in which students can

explore mathematical structures dynamically and interactively. This approach supports the formation of key analytical competencies and fosters the development of independent problem-solving skills. The examination of combinatorics and probability theory illustrates the pedagogical value of computational modeling in reinforcing theoretical knowledge and enabling students to investigate patterns and structural relationships that are often difficult to capture through traditional methods.

The ideas presented here allow us to formulate several conclusions regarding the methodological application of computer modeling in the teaching of higher mathematics.

1. The integration of computer modeling enhances the effectiveness of mathematical instruction by providing dynamic representations of abstract concepts and reducing the cognitive burden associated with complex manual computations.

2. The use of the Maple system strengthens students' analytical and structural reasoning by enabling the exploration of symbolic expressions, probabilistic models, and combinatorial constructs in an interactive computational environment.

3. The methodological approach developed in this work offers a coherent framework for incorporating computational tools into the study of higher mathematics while maintaining the rigor and conceptual precision of classical instruction.

4. Computer modeling supports the development of practice-oriented competencies, preparing students for professional activities that require the application of mathematical reasoning to real-world problems in science, engineering, and technology.

Overall, the methodological foundations presented in this article emphasize the necessity of integrating computer modeling into the mathematical preparation of students in technical fields. By combining theoretical exposition with computational tools, educators can create a more effective, engaging, and intellectually rich learning environment. This integration not only improves the quality of mathematical education but also aligns with broader trends in the modernization of technical curricula, ensuring that students acquire the knowledge and skills required for contemporary scientific and technological practice.

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