# Mathematics Problems and Computer Algebra Systems as Didactic Tools for Developing the Professional Competence of Bachelors in Mathematics and Computer Science

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Abstract: The article examines how mathematics problems and computer algebra systems (CAS) contribute to professional competence development in future bachelors of mathematics and computer science. It justifies adopting didactic approaches responsive to higher-education digitalization and the integration of information technologies into instruction. Problems are treated not merely as routine exercises but as multifunctional tools for fostering critical and creative thinking, research skills, and analytical reasoning. The paper outlines a classification of problems used in university training and discusses their methodological value. It is argued that combining conventional solution strategies with CAS automates routine computations while focusing learning on conceptual understanding, mathematical modeling, algorithm design, and interpretation of results. The methodologically structured examples of tasks substantiate the feasibility of an integrated approach that combines classical mathematical methods, task-based learning, and digital support for the problem-solving process. Systematic CAS use is shown to increase motivation and strengthen digital literacy, information culture, and academic integrity. Future research should focus on refining the criteria for assessing the effectiveness of the proposed approach, broadening the experimental sample, and investigating the potential of artificial intelligence technologies to support the personalization of the educational process.

## 1 INTRODUCTION

Modern higher education is oriented toward the development of individuals capable of critical thinking, self-directed learning, and effective application of knowledge in professional practice. A leading trend in its development is the competency-based approach, which involves the integration of theoretical knowledge, practical skills, and experience in solving complex and ill-defined problems. This approach is particularly relevant in the training of future bachelors in mathematics and computer science, whose professional competence is defined by their ability to perform mathematical modeling, data analysis, and to use modern computational technologies.

According to the Standard of Higher Education for Specialty 111 “Mathematics,” integral competence is defined as the ability to solve complex tasks and practical problems using methods of mathematics, statistics, and computer technologies under conditions of uncertainty [1]. General and professional competencies, as well as learning outcomes, are aimed at the development of abstract thinking, mathematical analysis, construction and investigation of models, and the application of numerical methods and computational tools.

A similar approach is implemented in the Standard of Higher Education for Specialty 014 “Secondary Education (by subject specializations),” where integral competence is defined as the ability to solve complex specialized problems in the field of education [2]. Thus, both standards emphasize the central role of problem-solving activity as the foundation of professional training for future specialists.

In training bachelors in Specialty 014.09 “Secondary Education (Computer Science),” emphasis is placed on constructing information models, conducting computer-based experiments, and analyzing results to solve problems of varying complexity. This fosters algorithmic thinking, research skills, and readiness to apply mathematical and digital technologies in professional practice.

An important factor in enhancing the effectiveness of problem-based training is the use of CAS, which integrate numerical and symbolic computations and support modeling and investigation of mathematical objects. Their implementation in the educational process creates conditions for deeper problem analysis, comparison of different solution methods, and the development of students' analytical and critical thinking.

Analysis of recent research and publications. Problem solving in contemporary didactics of mathematics and computer science is regarded as a key integrative component of the educational process and a foundation for the formation of subject-specific and meta-disciplinary competencies. Researchers emphasize its system-forming role and interdisciplinary nature [3].

Studies [4], [5] substantiate the problem-based approach as a leading pedagogical strategy that spans all stages of learning and involves the use of digital and dynamic computer models for visualization, exploration, and experimentation. At the same time, empirical research reveals persistent difficulties among students in the mathematical formalization of real-world situations and model construction, particularly in context-based problems such as those used in PISA assessments [6].

The professional dimension of the problem-based approach is reflected in studies focused on the training of future teachers of mathematics and computer science, including problems with parameters [7], cascade problems as a means of competence formation and assessment [8], and educational-methodological problems that model authentic teaching practice [9]. Recent research also highlights the growing role of computational thinking as a conceptual framework for problem solving, whose stages are functionally aligned with classical strategies of problem analysis [10].

A number of studies emphasize the specificity of computer science problems as modeling-, research-, and interdisciplinary-oriented tasks, the solution of which involves formalization, algorithm design, program implementation, and result analysis [11], [12]. Attention is also drawn to the potential of artificial intelligence for problem selection and classification aimed at personalized learning [13]. Experience in applying computer algebra systems confirms the effectiveness of the problem-based approach in shaping the professional culture of future specialists in mathematics and computer science [14], [15].

The purpose of this article is to substantiate theoretical and practical approaches to the use of problems and computer algebra systems in forming the professional competence of future bachelors in mathematics and computer science -and to identify opportunities for their integration into the educational process to develop the ability to analyze, model, and solve professionally oriented problems.

# 2 THEORETICAL FOUNDATIONS OF THE STUDY

In contemporary mathematics education, the concept of a "task" extends well beyond a simple computational question based on given conditions. Researchers define a task as a cognitive situation in which the subject must identify the problem, construct an appropriate mathematical model, and formulate potential solution strategies [16]. Problem posing is regarded as a staged activity involving understanding of the problem statement, problem construction, and its formulation as a mathematical proposition [17]. In pre-service mathematics teacher education, the ability to design high-quality realistic tasks is considered a key component of professional competence requiring purposeful development [18].

Accordingly, in the process of teaching mathematics and computer science, problems serve as the primary means of organizing students' learning-cognitive and research activities and fulfill motivational, instructional, developmental, educational, managerial, and assessment functions. Various types of problems are used within academic disciplines, including algorithmic, semi-algorithmic, heuristic, computational, proof-based, and applied problems. Therefore, the sequence of practical classes should be designed with regard to the diversity of problems that have a problem-oriented and, in particular, non-standard character; ensure a gradual increase in students' independence.

Numerous approaches to the classification of mathematics problems are presented in scientific and methodological sources. Their generalization and systematization are presented by the authors in the form of an original classification (Fig. 1).

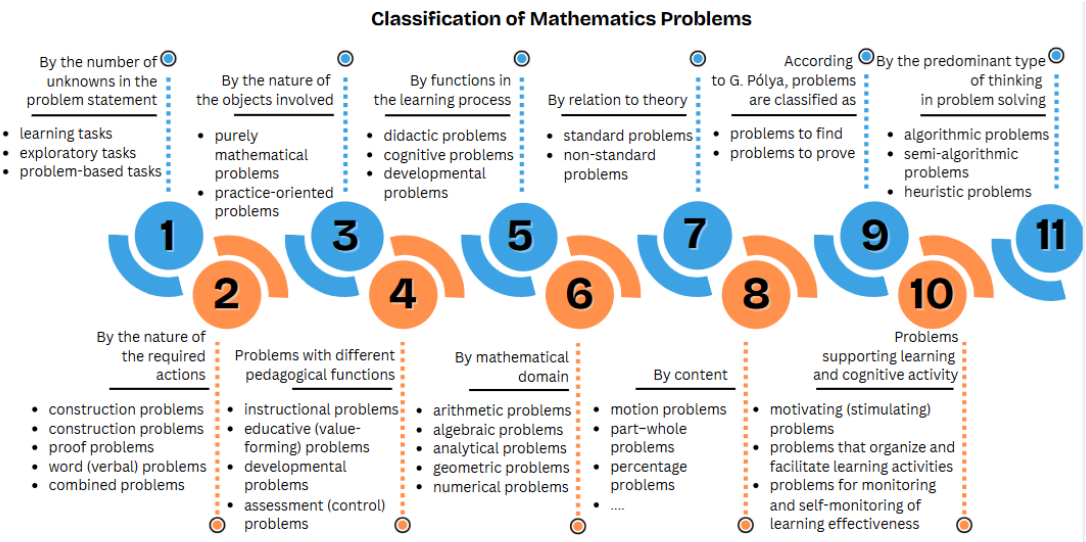


Figure 1: Classification of mathematics problems (authors' generalization and systematization of existing scientific and methodological approaches).

For developing professional competencies, it is advisable to use problems with parameters, research-oriented, experimental, applied, interdisciplinary problems, and problems requiring multiple solution methods. Such problems foster creative thinking, analytical and generalization skills, method transfer, and decision-making in alternative situations.

General competencies related to the use of information and communication technologies [1], [2] imply students' ability to solve educational and professional problems by means of digital technologies, including the use of computer algebra systems, while adhering to the principles of academic integrity and digital security.

Thus, problems and tasks related to problems constitute an important didactic tool for forming the professional competencies of future specialists in mathematics and computer science, and their integration with digital technologies complies with contemporary educational standards and the requirements of professional training.

# 3 RESEARCH RESULTS

Problem solving is a key factor in shaping students' mathematical culture, including mathematical thinking, language, and professional competencies. The development of a bachelor's skills in mathematics proceeds in stages: at the first stage – through mastering problem solving; at the second – through independent problem posing and construction. Engaging students in creating problems and research objects facilitates a shift from reproducing known results to generating new knowledge, promotes the development of logical thinking, and supports a systematic entry into research activity.

This section presents a representative set of problems from mathematical and computer science disciplines, oriented toward the training of students in Specialties E7 "Mathematics," A4.04 "Secondary Education (Mathematics)," and A4.09 "Secondary Education (Computer Science)." The problems are provided in a standardized format: statement and context; formalization and selection of methods; stages of solution and verification of results. Solutions are carried out using computer algebra systems and digital technologies.

Study [19] underscores the broad role of computational tools in mathematical research, demonstrating their applicability to nonlinear equations, polynomial analysis, and numerical methods, thereby highlighting their potential for mathematical problem solving.

The proposed approach is methodologically characterized by the integration of task-based learning, classical mathematical methods, and digital support for problem solving. Rather than treating tasks as isolated exercises for reproducing algorithms, this study considers them as multicomponent didactic units involving problem formulation, mathematical modelling, method selection, solution implementation, computer-assisted verification, interpretation of results, and reflection. This organization of task-based activity, rather than any single digital tool, is regarded as a key factor in improving learning outcomes. Against this background, the following section presents methodologically structured examples of tasks from mathematical analysis, numerical integration, and computer science teaching methodology.

*The first example illustrates a cognitive task in mathematical analysis, focusing on the theory of limits (DSc in Pedagogy, Prof. Mariana Kovtoniuk).*

Let $A$ and $B$ be two finite sets. We pose the question whether these sets contain the same number of elements. One may proceed by enumerating the elements of each set and then comparing the results. However, it is also possible to proceed differently, without counting the elements. A characteristic feature of this method of comparing sets is that, for each element of one set, exactly one corresponding element of the other set is specified, and conversely. The advantage of this method is that it can be applied even when the sets being compared are *infinite*!

**Problem 1.** Prove that the set of points of an arbitrary interval $(a; b)$ is equivalent to the set of real numbers $R$.

***Proof.*** Consider the composition of mappings $(a; b) \xrightarrow{f} \left(-\frac{\pi}{2}; \frac{\pi}{2}\right) \xrightarrow{g} R$. It is clear that the function $f(x) = \frac{\pi}{b-a}(x-a) - \frac{\pi}{2}$ is a one-to-one correspondence between $(a; b)$ and $\left(-\frac{\pi}{2}; \frac{\pi}{2}\right)$, and the function $g(x) = \tan x$ is a one-to-one correspondence between $\left(-\frac{\pi}{2}; \frac{\pi}{2}\right)$ and $R$ (Fig. 2).

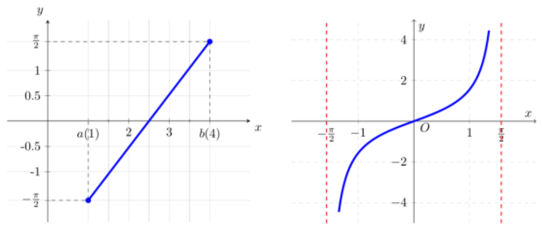

Figure 2: Visualization of the solution to Problem 1.

Then the composite function $g(f(x)) = \tan\left(\frac{\pi}{b-a}(x-a) - \frac{\pi}{2}\right)$ is a one-to-one correspondence (bijection) between the sets $(a; b)$ and $R$. Thus, we see that an interval contains as many points as the entire real line. Problems of this kind quite often come as a surprise to higher-education students at the beginning of studying the topic "Equivalent Sets."

*The second example presents a didactically oriented task in mathematical analysis that admits several solution methods (DSc in Pedagogy, Prof. Mariana Kovtoniuk).*

**Problem 2.** Find all values of the parameter $a$, $a > 0$, for which the inequality $\int_{-a}^{a} e^x\,dx > \frac{3}{2}$ holds.

***Solution:***

**Method 1.** Since $\int_{-a}^{a} e^x\,dx = e^x|_{-a}^{a} = \; = e^a - e^{-a}$, the given inequality is equivalent to $e^a - e^{-a} > \frac{3}{2}$, hence $\frac{2e^{2a} - 3e^a - 2}{2e^a} > 0$. Because $e^a > 0$ for all $a$, it follows that $2e^{2a} - 3e^a - 2 > 0$, or, equivalently, $e^a > 2$. Therefore, all values of $a$ satisfying the original inequality are $a > \ln 2 \approx 0.6$.

**Method 2.** (using the dynamic geometry software GeoGebra).

1) Create a slider $a$, $(a > 0)$;
2) In the Input Bar, define the functions: $f(x) = e^x$ and $g(x) = \frac{3}{2}$;
3) Compute the integral; for this purpose, from the suggested functions select Integral [f, a, b], where, $a = -a$ and $b = a$;
4) n the Input Bar, enter the inequality $b > g(x)$; by moving the slider, vary the parameter $a$ and observe the solutions of the inequality.

In the case when $a \in 0; 0.6$ the inequality is not satisfied (Fig. 3).

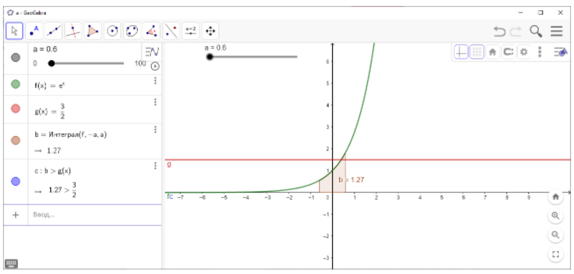

Figure 3: Visualization of the solution to Problem 2 under the condition that $a = 0{,}6$.

In the case when $a \in (0.6;\ +\infty)$, the inequality holds. Hence, the inequality is satisfied for $a \in (0.6;\ +\infty)$.

*The third example provides an educational and methodological interpretation of a proof task based on the classical definition of the limit of a sequence (DSc in Pedagogy, Prof. Mariana Kovtoniuk).*

**Problem 3.** Using the definition of the limit of a sequence, prove that $\lim_{n\to\infty} \frac{5\cdot 3^n}{3^n - 2} = 5$.

At the preparatory stage, students independently compute the first few terms of the sequence and formulate a conjecture regarding its possible limit. Digital tools, including calculators, CAS, and artificial intelligence systems, are used not as means of proof but as auxiliary instruments for verifying numerical observations and supporting the subsequent critical analysis of the conjecture. The numerical behavior of the sequence and its apparent convergence are illustrated in Figure 4.

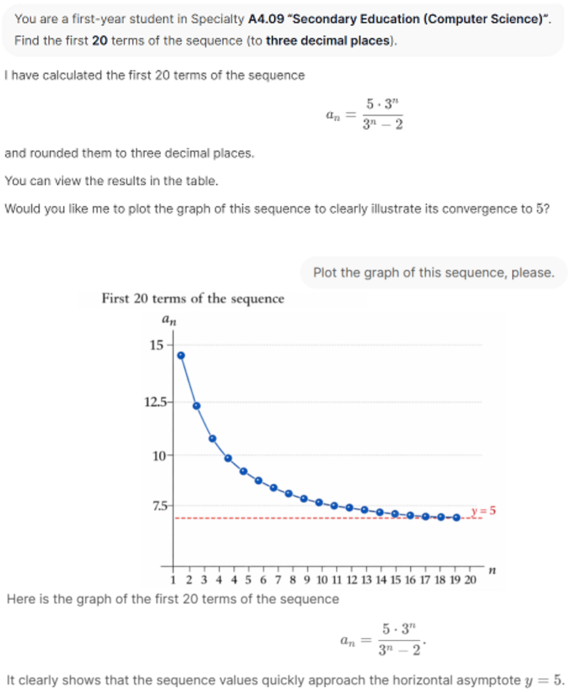


Figure 4: Investigation of the convergence of a numerical sequence.

The final justification is provided using the classical method based on the definition of the limit of a sequence. We observe that the terms of the sequence approach 5. Therefore, we hypothesize that the limit of the sequence is 5 and prove this claim using the formal definition of the limit.

**Strategy.** According to the definition of a limit, for any arbitrarily small positive number $\varepsilon > 0$ we must specify an index $n_0$ such that, whenever $n > n_0$, the inequality $|y_n - a| < \varepsilon$ holds.

**Proof.** $\left|\frac{5 \cdot 3^n}{3^n - 2} - 5\right| < \varepsilon \Leftrightarrow \frac{10}{3^n - 2} < \varepsilon, 3^n > \frac{10}{\varepsilon} + 2.$

Taking the logarithm base 333 of the last inequality, we obtain $n > log_3\left(\frac{10}{\varepsilon} + 2\right) \geq \left[log_3\left(\frac{10}{\varepsilon} + 2\right)\right] = n_0$.

Hence, for every $\forall \varepsilon > 0$ we can choose $n_0$ such that for all $\forall n > n_0$, $\left|\frac{5 \cdot 3^n}{3^n - 2} - 5\right| < \varepsilon$.

*The fourth example demonstrates the solution of a numerical integration task using the classical Newton–Cotes formula and CAS Maxima (PhD in Pedagogy, Assoc. Prof. Olena Soia).*

**Problem 4.** Evaluate, using the Newton–Cotes formula, the integral $\int_0^1 \frac{x}{1+\sqrt{x}} dx$ by partitioning the integration interval into five equal subintervals.

***Solution.*** The Newton–Cotes formula for $n = 5$ - has the form:

$$I_5[f] \approx \frac{5}{288} h(19f(x_0) + 75f(x_1) + 50f(x_2) + +50f(x_3) + 75f(x_4) + 19f(x_5)).$$

where $h$ is the step size.

Computing a definite integral by approximate methods reduces to performing a sequence of numerical operations on the integrand. Accordingly, this problem can be classified as a numerical one. For the practical implementation of the computations, the functional capabilities of the CAS *Maxima* were used.

We specify the function $f(x)$, the number of subintervals, and the limits of integration. Next, we determine the step size for partitioning the integration domain into five subintervals (six nodes). Substituting the obtained values into the Newton–Cotes formula for $n = 5$ yields an approximate value of the integral.

```
(%i1) f(x):=x/(1+sqrt(x))$
(%i5) n:5$ x0:0$ x5:1$ h:(x5-x0)/n$
(%i10) x1:x0+h$  x2:x0+2*h$
       x3:x0+3*h$  x4:x0+4*h$
       x5:x0+5*h$
(%i11) 5/288*h*(19*f(x0)+75*f(x1)+
       50*f(x2)+50*f(x3)+75*f(x4)+
       19*f(x5)),numer;
(%o11) 0.2801851383917844
```

We compute the value of the integral using the built-in **Numerical integration** function in the *Maxima* CAS.

```
(%i12) J:romberg(f(x),x,0,1);
(%o12) 0.2803708091994577
```

The absolute error (residual) is:

```
(%i13) R:abs(J-I), numer;
(%o13) 1.856708076732327*10^-4
```

On the other hand, this problem can reasonably be regarded as algorithmic, since it involves a clearly defined sequence of steps: partitioning the interval into equal subintervals; evaluating the function at the nodes; substituting these values into the Newton–Cotes formula; and obtaining an approximate value of the integral. These steps can be readily formalized as an algorithm and implemented programmatically using computer mathematics systems (e.g., Maxima, Maple, Mathematica, etc.) or general-purpose programming languages (Python, C++, Java, etc.).

```
(%i1) f(x):=x/(1+sqrt(x))$
(%i3) a:0$ b:1$
(%i5) n:5$ h:(b-a)/n$
(%i6) create_list(x[i]:a+h*i,i,0,n)$
(%i7) H(i):=1/n*(-1)^(n-i)/(i!*
       (n-i)!)*integrate(product
       ((q-k),k,0,n)/(q-i),q,0,n)$
(%i8) I:(b-a)*sum(H(i)*f(x[i]),
       i,0,n),numer;
```

An algorithmic formulation of this problem makes it possible to obtain a solution in a finite number of steps by specifying in program code the integrand, the limits of integration, and the number of partition nodes. Thus, the problem pertains not only to numerical integration but also has a pronounced algorithmic character, since its solution is based on a computational algorithm suitable for implementation using programming tools.

The fifth example considers the methodological use of the “Starry Sky Projector” task, proposed for Stage II of the All-Ukrainian School Students’ Olympiad in Information Technologies in the 2025–2026 academic year [20], within the course “Methods of Teaching Computer Science,” particularly when studying the topic “Methods for Teaching the Modelling of Information Processes” (PhD in Pedagogy, Assoc. Prof. Olena Kosovets).

**Problem “Starry Sky Projector.”** Using a spreadsheet application, create an interactive model of a starry-sky projector that simulates changes in the night-sky color and the number of stars according to specified parameters [20].

***Solution.*** To complete the task, we use the following spreadsheet functions and tools:

1) `=IF(condition, value_if_true, value_if_false)` – the main logical function that determines whether to display a star in a given cell by checking the output of a random number.
2) `=RAND()` – generates a random decimal number in the interval 0,1). It serves as a probability generator for star appearance (the value is compared with the percentage set via the scroll bar).
3) `=RANDBETWEEN(1,2)` – generates a random *integer* within the specified bounds. It is used to randomly select the star type: 1 (white) or 2 (yellow).
4) `Conditional Formatting` (menu tool) – used for visualization: it converts the numbers 1 and 2 into white/yellow stars and changes the background (sky) color depending on the second slider.
5) `Developer tab → Scroll Bar` – a form control that allows users to change cell values without manual data entry, thereby ensuring interactivity (Fig. 5).

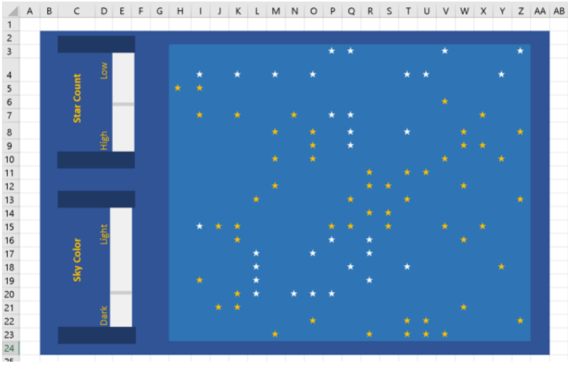


Figure 5: Implementation of the “Starry Sky Projector” task.

By completing this project, prospective specialists develop advanced subject-specific competencies, in particular spreadsheet-based mathematical modeling, where dynamic processes are simulated rather than static computations performed. They learn to use pseudorandom number generators to control object density and to construct branching algorithms via logical functions, which constitute a foundation of any programming language.

# 4 DISCUSSION

The research methodology was grounded in the staged organization of students’ task-based activities using classical mathematical methods, CAS, and digital tools. Rather than introducing new solution methods, the approach focused on the didactically justified structuring of task solving: problem analysis, model formalization, method selection, analytical or numerical transformations, CAS-based verification, data interpretation, and reflection on the applicability of the chosen approach.

The study sample comprised 61 students at the Faculty of Mathematics, Physics and Computer Science, Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University, Ukraine. The sample composition was specified by educational programme, year of study, and student specialization. Tasks from different disciplines were used to assess integrated professional competence rather than knowledge of individual courses. All tasks were evaluated using unified criteria covering analytical, algorithmic, digital, and reflective components.

To test the significance of the changes, the Wilcoxon signed-rank test for paired samples was applied. Let the student's competence level before the experiment be denoted by $x_i$, and after the experiment by $y_i$.

Mean values: $\overline{X}_{pre} = 72.4$, $\overline{X}_{post} = 81.6$.

Difference between means: $\Delta\overline{X} = 9.2$.

After ranking the differences, we obtained:

$T^+ = 820, T^- = 45, T = min(T^+, T^+) = 45$.

Since $T = 45 < T_{crit}(0.05; n = 61) = 200$, the changes are statistically significant ($p < 0.001$).

Additionally, the gain coefficient was calculated:

$$I = \frac{\overline{X}_{post} - \overline{X}_{pre}}{\overline{X}X_{pre_{max}} \frac{81.6 - 72.4}{100 - 72.4}},$$

where $\overline{X}_{max}$. The value $I > 0.3$ indicates sufficient effectiveness of the proposed approach.

Thus, a positive shift ($y_i > x_i$) was observed for the majority of participants.

Effect size (Cohen's $r$): $r = \frac{z}{\sqrt{n}} \approx 0.62$, which corresponds to a large effect.

The results confirm the effectiveness of integrating problems and CAS in developing the professional competence of future bachelors in mathematics and computer science. Improved learning outcomes suggest that problems function not only as computational exercises but also as tools for developing students' research skills.

# 5 CONCLUSIONS

The study substantiates the importance of the task-based approach and CAS in developing the professional competence of future bachelors of mathematics and computer science. Tasks of various types are shown to be an effective tool for fostering critical thinking, research skills, algorithmic culture, and the ability to justify the choice of problem-solving methods. The use of CAS supports the automation of routine computations, result verification, visualization of mathematical relationships, and the integration of analytical and computer modelling, without substituting students' own mathematical reasoning. The methodologically structured examples of tasks substantiate the feasibility of an integrated approach that combines classical mathematical methods, task-based learning, and digital support for the problem-solving process. Future research should refine the criteria for assessing the proposed approach, broaden the experimental sample, and investigate the potential of AI technologies to personalize the educational process.

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