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Model for Organizing the Process of Working with Mathematical Information

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Abstract: The subject of Calculus is an integral part of the professional training of first-year bachelor's degree students specializing in mathematics at higher educational institutions. This study addresses the common difficulties students face when transitioning from school to university-level mathematics, such as inadequate foundational skills and challenges with the specific, often abstract, language of mathematical texts. The paper proposes a comprehensive methodological model aimed at enhancing students' ability to work effectively with mathematical information. The model is structured around four key components: purposeful, content-related, organizational-methodological, and result-oriented. The methodology, grounded in systematic and personalized approaches, incorporates modern pedagogical principles and utilizes various teaching tools, including information and communication technologies (ICT) and artificial intelligence (AI). An experimental verification involving a sample of 60 first-year students confirmed that the implementation of this model significantly increases the efficiency of their work with mathematical information.

Keywords: Mathematical analysis, pedagogical model, information competence, university education, student readiness.

INTRODUCTION

Calculus is a core subject for first-year mathematics students, but many struggle with the transition due to insufficient preparedness and the specific nature of mathematical texts, which often contain "gaps" in detailed explanations. This creates a need for a specific methodological model to ensure effective learning. This paper presents such a model, designed to help first-year students develop their skills in working with mathematical information. We link this methodology to a comprehensive **methodological system** for teaching Calculus, building on traditional pedagogical systems and incorporating contemporary research. The model is structured around four key components: purposeful, content-related, organizational-methodological, and result-oriented. The primary goal is to improve students' ability to work with mathematical information by developing a methodology and testing its practical effectiveness.

MATERIALS AND METHODS

This study utilized a quasi-experimental design to test the effectiveness of a proposed methodological model. The research was conducted with 290 first-year bachelor's degree students from a pedagogical university, all enrolled in the "Mathematics" program. The students were divided into two groups: an experimental group (EG) of 150 students and a control group (CG) of 140 students. To ensure a valid comparison, the groups were matched based on their prior academic performance using high school graduation scores and initial diagnostic tests in mathematics. The EG was taught using the new methodological model, while the CG followed the traditional curriculum.

The Proposed Methodological Model

The methodological system was developed based on the traditional teaching approach by A. M. Pishkalo (1970s) but adapted to incorporate contemporary research.

It is built upon systematic, active, and personalized learning approaches and consists of four main components:

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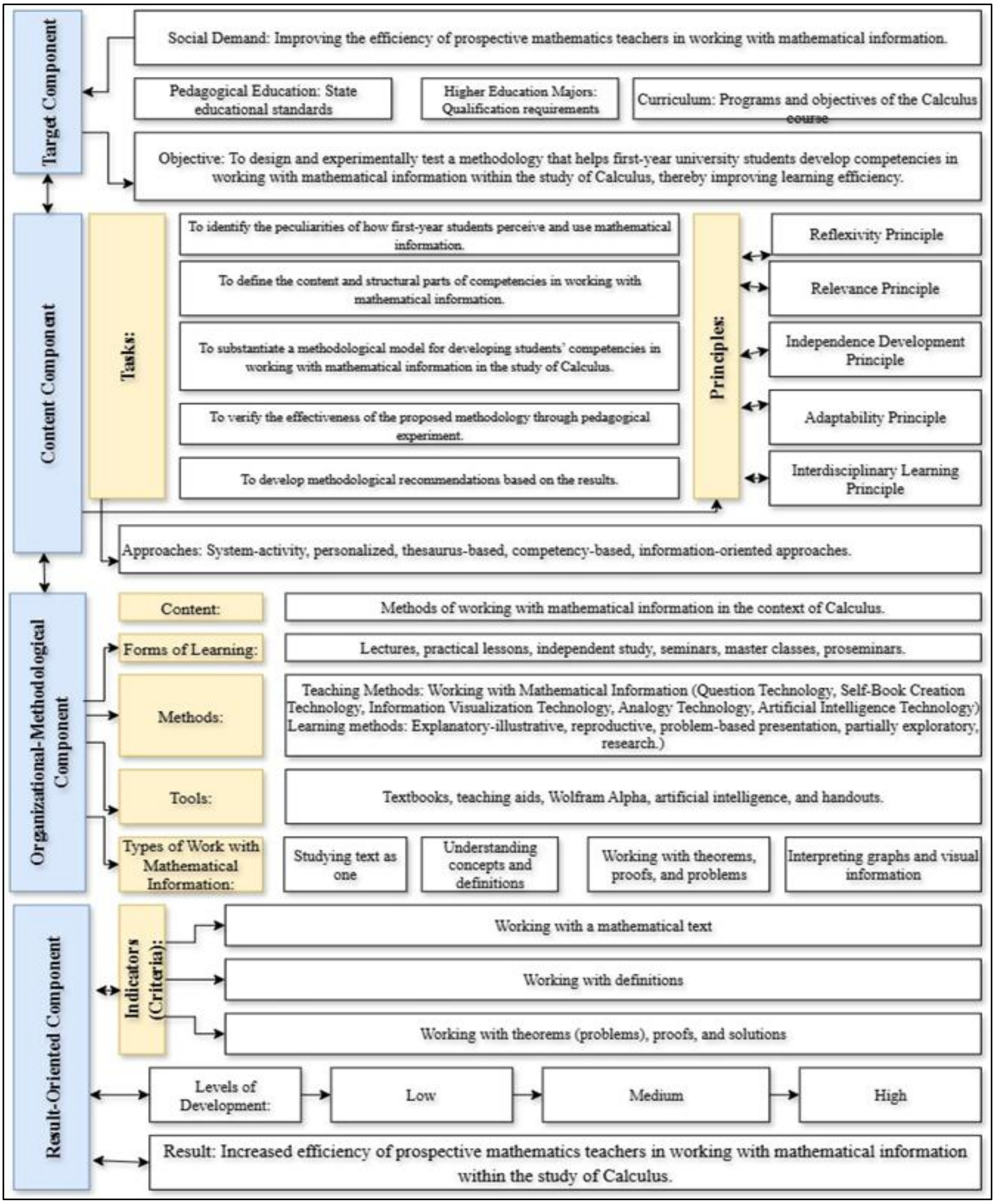

Purposeful Component: The overarching goal is to enhance students' ability to work with mathematical information. The objective is to develop and test a new methodology to cultivate competence in this area.

Content Component: This component specifies the tasks required to achieve the study's goals. The content is structured into four **didactic units**: working with pure mathematical text, concepts and definitions, theorems and proofs, and graphs and visual information.

Organizational-Methodological Component: This component outlines the practical implementation of the methodology. It includes a variety of teaching methods, such as explanatory-illustrative and problem-based learning. The

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formats of instruction include lectures, practical sessions, seminars, and master classes. The key resources and tools used were textbooks, handouts, and modern technology, including ICT and AI tools like ChatGPT, PhotoMath, and Wolfram Alpha. The model is also guided by several key principles:

- **Principle of reflexivity:** Encourages students to analyze and refine their own thought processes.
- **Principle of relevance:** Tailors education to the specific needs and characteristics of the students.
- **Principle of developing independence:** Fosters independent learning and problem-solving skills.
- **Principle of adaptability:** Allows the learning process to be adjusted to changing conditions.
- **Interactive learning approach:** Promotes cooperation and active communication between students and teachers. The model also integrates thesaurus-based, competency-based, and information-based approaches to
- **further enhance learning. Result-Oriented Component:** This final component is focused on monitoring and evaluating learning outcomes. Student progress was assessed using a three-level scale for their Universal **Learning Activities (ULAs):** low (reproductive), medium (productive), and high (creative).

Data Collection and Assessment

The assessment of students' ULA levels was conducted at two points: a **pre-test** at the beginning of the semester and a **post-test** at the end. The tests were specifically designed to evaluate skills across the four didactic units of content. For instance, tasks included:

- **Pure Text:** Analyzing and summarizing a complex mathematical text.
- **Concepts and Definitions:** Providing precise definitions and examples.
- **Theorems and Proofs:** Independently reproducing or constructing a proof.
- **Graphs and Visual Information:** Interpreting and explaining the properties of functions from their graphs.

The gathered data was analyzed using statistical methods. A **two-sample t-test** was used to compare the mean scores of the EG and CG, while a **chi-square test** was used to compare the distribution of students across the three ULA levels between the two groups. This rigorous statistical analysis ensured the validity of the results.

RESULTS

The data collected from the pre- and post-tests demonstrated a significant improvement in the experimental group's ability to work with mathematical information compared to the control group.

Two assessment points were established:

- **Pre-test** (at the beginning of the semester) to identify baseline skills.
- **Post-test** (at the end of the semester) to measure progress.
- **Retention test** (one month later) to evaluate long-term knowledge retention.

Student progress was assessed across three domains:

- Cognitive: comprehension of mathematical concepts and definitions.
- Analytical: ability to extract logical structure, proofs, and arguments from a text.
- Practical-Applicative: ability to apply information to solving problems and interpreting graphs.
- Statistical analysis included descriptive statistics, a two-sample t-test for mean differences, and a chi-square test for distribution of Universal Learning Activities (ULAs) levels.

QUANTITATIVE RESULTS

Table 1. Cognitive Engagement (mean scores)

Group	Pre-test	Post-test	Retention test
EG (150)	2.45	4.32	4.41
CG (140)	2.47	3.35	3.40

Table 2. Analytical Engagement (mean scores)

Group	Pre-test	Post-test	Retention test
EG (150)	2.50	4.28	4.36
CG (140)	2.48	3.30	3.38

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Table 3. Practical-Applicative Engagement (mean scores)

Group	Pre-test	Post-test	Retention test
EG (150)	2.42	4.25	4.34
CG (140)	2.44	3.28	3.35

Table 4. Distribution of ULA Levels in Experimental Group

ULA Level	Experimental Group (Pre-test)	Experimental Group (Post-test)
Low	90 (60%)	35 (23.3%)
Medium	50 (33.3%)	75 (50%)
High	10 (6.7%)	40 (26.7%)

Statistical Analysis

- **Average Scores**: The post-test mean score for EG was significantly higher (**M = 85.2, SD = 5.1**) than for CG (**M = 68.4, SD = 7.3**). A two-sample t-test confirmed the difference (**$t(288) = 17.52$, $p < 0.01$**).
- **Distribution of ULA Levels**: A chi-square test confirmed a significant difference between EG and CG at the post-test stage (**$\chi^2(2, N=290) = 48.7$, $p < 0.01$**).

DISCUSSION

The results indicate that the proposed methodological model substantially enhances students' ability to work with mathematical information. Unlike the control group, EG students showed:

- higher confidence in analyzing and summarizing texts;
- improved ability to define, prove, and apply mathematical concepts;
- stronger retention of knowledge, as demonstrated in delayed testing.
- The integration of ICT and AI tools proved particularly effective, fostering independence and providing immediate feedback.

Qualitative Observations

Beyond the numbers, observations during the study showed a tangible shift in student behavior. Students in the experimental group became noticeably more confident and proactive in their learning. They demonstrated a greater willingness to engage with challenging mathematical texts, actively sought clarification through questions, collaborated more effectively on complex problems, and independently used digital resources to verify their understanding. This qualitative feedback aligns with and reinforces the significant quantitative improvements.

DISCUSSION

The results of this study strongly support the effectiveness of the proposed methodological model. The significant increase in the experimental group's test scores and the shift of students to higher ULA levels confirm that the model successfully addresses the initial difficulties students face. Unlike traditional methods that often focus on rote memorization, our model, based on reflexivity, adaptability, and an interactive learning approach, encourages a deeper engagement with the subject matter. The systematic breakdown of mathematical information into didactic units allows students to gradually build competence, from understanding basic concepts to independently proving theorems.

The integration of ICT and AI tools also proved to be a powerful factor, empowering students to process information more efficiently and visualize complex concepts. This finding aligns with recent research on the role of digital technologies in modern education.

While the study's results are promising, it is important to acknowledge its limitations, such as the relatively small sample size and the focus on a single university. Future research should include a larger, more diverse student population and explore the model's adaptability to other STEM disciplines.

CONCLUSION

The methodological model for working with educational mathematical texts has been validated as an effective tool for first-year bachelor's students in a mathematics program. By using this model, students successfully develop the mathematical competencies essential for their future pedagogical careers. The model provides a structured and adaptable approach to help students overcome the learning gap and engage effectively with complex mathematical information.

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