The Mathematical Competence of a Future Engineer as a Unity of Gnoseological, Praxiological and Axiological Components

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ABSTRACT

The article is devoted to the study of the formation of mathematical competence of students of a technical university in the process of studying mathematics and is based on the materials of the author's dissertation research. The choice of this direction in the study of competence is relevant and promising in terms of improving the modern professional education of future engineers in the oil and gas industry. The author analyzes in detail the state of the problem under study in pedagogical theory and practice; examines key research concepts; defines approaches to solving the problem of forming the mathematical competence of a future oil and gas engineer. The data of the theoretical analysis of the problem formed the basis for the development of a structural-meaningful model of the formation of the mathematical competence of a future engineer in the oil and gas business, in which the author includes target, meaningful, activity-procedural, productive-evaluative components. The effectiveness of the model being implemented and the pedagogical conditions that ensure its effective functioning is confirmed by the dynamics of changes in the level of formation of students' mathematical competence. The data of the initial and final stages of the experimental work, presented in the tables, clearly illustrate the dynamics and positive results of the study. The conclusions formulated in the conclusion of the study confirm the heuristic value of the work performed and reveal new lines of development of the indicated problem, potentially embedded in the study.

Keywords: mathematical competence, learners, mathematics, higher education, experiment.

1. Introduction

In recent decades, the processes of globalization have covered more and more spheres of life, including education. One of these processes is the joint integration of European countries into the common European educational space. One of the leading directions of modernization of vocational education is the formation of the professional competence of an individual as a complex multifunctional structure.

Rapid updating of technologies and equipment requires from modern specialists not only a sum of knowledge and skills, but the ability to quickly master new knowledge, adapt to changes in production and society, and work in a team. New requirements for university graduates entail changes in the education system: new state educational standards are being created, training programs are being changed, the concept of specialist competence is being introduced.

Mathematical education is one of the basic elements of the system of professional training of future engineers of the oil and gas industry at the university. For students of engineering specialties, mathematics is not only an academic discipline, but also a tool for the analysis of professional activities, organization, and management of technological processes.
A graduate of a technical university in the field of "Oil and Gas Business" must:
- know: analytical and numerical methods for analyzing mathematical models of oil and gas processes; economic and mathematical methods when performing economic calculations and in the management process; methods of designing technological processes;
- own: mathematical apparatus and computer graphics for calculating the parameters of the technological process; methods for determining the optimal and rational technological modes of equipment operation.

The formed skills to apply the mathematical apparatus for the needs of engineering activity during the period of study at the university play an important role in solving these problems. Studying mathematics intellectually enriches the student by developing the flexibility and rigor of thought necessary for a future engineer. Therefore, one of the important qualities required for a future oil and gas engineer is mathematical competence.

Various aspects of professional competence represented the field of scientific interests of many researchers. Among them are Yu.V. Vardanyan, V.S. Lazarev, V.A. Slastenin and others (Vardanyan, 2008), (Lazarev, 2014), (Slastenin, 2006). The works of these authors reveal such important concepts for our research as “competence”, “professional competence”.

The basis for improving the training of an engineer was made up of general theoretical provisions disclosed in the works of E.Kh. Bashkaeva, O. V. Dolzhenko, O.S. Tamer (Bashkaeva, 2002), (Dolzhenko, 1990), (Tamer, 2002). Of particular interest to us are works that consider the features of the formation of engineering professionalism (A.A. Krylov, B.F. Lomov) (Krylov et al., 1979), (Lomov, 2013). However, at present, there is not enough research that reveals the specifics of the formation of the mathematical competence of engineers in the oil and gas business at the university, taking into account the capabilities of the system of higher engineering education.

Comprehension of the pedagogical experience and scientific literature shows that various aspects of the formation of the mathematical competence of a future oil and gas engineer are relatively new and insufficiently studied.

Despite a certain degree of theoretical elaboration of the indicated issues, graduates of a technical university have a low level of proficiency in the mathematical apparatus, they are not aimed at using it in professional engineering.

Thus, the analysis of psychological, pedagogical and methodological literature, the study of the experience of teaching a mathematics course at a university confirms the existence of a contradiction between the objective need of society to expand the professional, including mathematical, competence of oil and gas industry specialists and the insufficient scientific substantiation of its formation among students of technical specialties at all stages of training.

It is possible to change this situation, in our opinion, if the content of the educational process in mathematics at the university is oriented towards the new needs and requirements of society, namely, towards the formation of the mathematical competence of the future oil and gas engineer. This is a complex practical problem that requires appropriate scientific knowledge to successfully solve.

The need to resolve this contradiction determines the relevance of this study and determines its problem associated with the determination of the scientific foundations for the creation and implementation of the model and the pedagogical conditions for the effective formation of the mathematical competence of the future oil and gas engineer.

2. Methodology

The conducted categorical analysis of the concepts of "competence", "competence", "professional competence" (E.F. Zeer, I.F. Isaev, EF Nasyrova, A.V. Chutorskoy, M.A. Choshanov) (Zeer, 2004), (Nasyrova, 2007), (Khutorskoy, 2003), (Choshanov, 2016) "mathematical competence of a specialist" (V.G. Plakhova, G.L. Illarionova, V.P. Matveikina, E.V. Sergeeva) (Plakhova, 2008), (Illarionova, 2008), (Matveikina, 2012), (Sergeeva, 2016) made it possible to formulate the following definition: a mathematical competence of a future oil and gas engineer is a unity of epistemological, praxeological, axiological components that provide him with the ability to solve theoretical and engineering and practical tasks that are significant in the professional activity of a modern specialist in an engineering and technical profile.

Taking into account the study of numerous studies, we have identified three components of mathematical competence - epistemological, praxeological and axiological components, which reflect all the requirements for the quality of mathematical training of students of technical specialties.

The epistemological component of the mathematical competence of a future oil and gas engineer defines the knowledge system as a set of interconnected elements that represent a certain holistic education.

The praxeological component of the mathematical competence of a future oil and gas engineer combines a set of skills (constructing mathematical models, communicative, algorithmic, functional, geometric, stochastic), educational and life experience, allowing to operate with mathematical knowledge in the process of solving theoretical and practical engineering problems.
The axiological component of the mathematical competence of a future oil and gas engineer represents motives and interest in educational and future professional activities, professionally important qualities. This component performs the regulatory function of the ongoing pedagogical process.

The interrelation of these components reflects the holistic nature of the process under study, based on the interaction of the teacher and students, aimed at mastering students' knowledge and skills, at developing positive motivation and interest in their future professional activities.

Based on the obtained structure of mathematical competence, taking into account the competence-based approach as a methodological basis, we have developed a structural-meaningful model of the formation of the mathematical competence of a future oil and gas engineer (Fig. 1).

The structural-meaningful model of the formation of mathematical competence includes a number of interrelated components: target, meaningful, activity-procedural, productive-evaluative.

The target component reflects the goal and objectives of the process under study. The purpose of this process is to form students' mathematical competence, which allows them to solve theoretical and engineering-practical problems that are significant in the professional activities of a modern specialist in an engineering and technical profile at a sufficiently high level. The stated goal is realized in the tasks determined taking into account the structure and content of the concept "mathematical competence of a future oil and gas engineer".

The content component is interconnected with the target, activity-procedural, performance-evaluative components. It reflects principles and content. Substantial principles (fundamental; scientific; professional orientation) form the basis of the process of forming the mathematical competence of a future oil and gas engineer. Organizational and methodological principles (consistency and logical sequence; unity of group and individual training; feedback; accessibility with a sufficient level of difficulty; productivity and reliability) reflect the features of this process. And also this component includes the structured content of vocational education in the form of competencies (V.S. Lazarev), invariant to the field of professional activity.

The activity-procedural component involves the characteristics of methods, means and forms of organizing pedagogical interaction.

The process of forming the mathematical competence of a future engineer involves the use of different methods (explanation, method of demonstration, observation, discussion, encouragement, etc.), means (Internet resources, schemes, media, etc.) and forms of training organization (lecture-information, lecture with planned errors, lecture with current control, lecture-conference, scientific conferences, etc.).

The productive-evaluative component is interconnected with the target, meaningful, activity-procedural components; it involves analyzing the results, identifying deviations from the goal, the reasons for their occurrence and making the necessary adjustments.

The effective functioning of the structural-content model presupposes the need to identify a set of pedagogical conditions. Their selection was carried out on the basis of a theoretical analysis of the essence, features, structure of mathematical competence, as well as analysis of the results of the ascertaining stage of the experiment.

As the first pedagogical condition, we used the organization of training through the introduction of modular educational technology of training, which provides for program-targeted structuring of subject knowledge and algorithmization of generalized educational actions of students. This technology makes it possible to take into account most fully for each student and the group as a whole all the activities associated with the formation of mathematical competence, rationally organize the process under study, having a great influence on its effectiveness. Modular technology contributes to the disclosure of the value aspect of knowledge, the expansion of mathematical knowledge and skills to the level of mastering the skills of mathematical modeling.

This condition is more conducive to the formation of the epistemological component of mathematical competence.
The second pedagogical condition is to strengthen the practical orientation of the process under study through the use of professionally oriented mathematical problems. The introduction of professional-type tasks into the educational process teaches students to see the universality of mathematical formulas, leads to elements of mathematical modeling of professional tasks from various fields of science and technology. This condition contributes to the formation of the praxeological component of the investigated competence and ensures the practical orientation of the investigated pedagogical process.

The third pedagogical condition is the use of pedagogical monitoring and self-monitoring to obtain objective information about the effectiveness of the ongoing process and its operational correction. The main goal of pedagogical monitoring is a comprehensive characteristic of students' mathematical competence in order to correctly assess the level, causes of deviations arising under the influence of internal and external factors. Monitoring is a kind of control mechanism, a regulator of the process of forming mathematical competence; contributes to the identification of negative and positive factors affecting its quality. Along with pedagogical monitoring, self-monitoring is also of great importance, allowing students to determine the level of their mathematical competence and to correct their behavior.

The implementation of these pedagogical conditions in unity contributes to the integration of epistemological, praxeological and axiological components of the mathematical competence of the future engineer.

3. Results

The experiment was carried out in several stages: ascertaining (determining the initial level of the formation of mathematical competence among students), forming (organizing the educational process based on the developed model and taking into account the selected pedagogical conditions) and generalizing (final assessment of the results according to the selected criteria and indicators in the control and experimental groups, substantiation of the effectiveness of the selected pedagogical conditions).

Students of the direction “Oil and Gas Business” took part in the experimental work in the course of studying the course “Mathematics”. Since the results of our study apply to similar vocational training in the study of one subject, we decided to limit the number of participants in the experiment to 136.

At the first stage of the experimental work, the level of formation of the components of mathematical competence among students was determined, the state of each component of the investigated competence was studied, the presence of significant differences was revealed. In this regard, such methods were used as analysis of documentation, testing, questionnaires, conversations with students and teachers, observation, study of the products of students' activities, test diagnostics of knowledge and skills.
As criteria and indicators in assessing the levels of formation of the components of the mathematical competence of a future oil and gas engineer, the following were singled out: cognitive (indicators - the volume, meaningfulness of acquired knowledge and the speed of task completion); activity (indicators - the ability to acquire knowledge on their own and the ability to apply the acquired knowledge in practical and laboratory classes in practical activities, as well as the ability to transfer skills to other tasks); motivational (indicators - the degree of development of positive motivation, the stability of interest, the nature of the attitude and the predominance of types of motivation for future professional activity).

When assessing the level of formation of mathematical competence, it was important for us to identify not only the possession of knowledge, but also the ability to apply it in solving theoretical and engineering-practical problems. In accordance with the above criteria, the levels of the formation of the mathematical competence of the future oil and gas engineer were determined: low, medium, high. The high level is the actual mathematical competence, and the middle and low are the necessary stages on the way to achieving it.

The results of the ascertaining stage of the experiment, presented in Table 1, indicate that most of the students have low (64%) and medium (20.6%) levels of mathematics competence formation. Most of them possess only some incomplete theoretical knowledge, but experience difficulties associated with the inability to use the mathematical apparatus for solving practical engineering problems. The absence of a value understanding of the professional significance of the course “Higher Mathematics” was found. This confirmed the presence of shortcomings in the system of mathematical education of students of technical specialties and necessitated purposeful work in order to increase the effectiveness of the process under study, including the implementation of a set of selected pedagogical conditions.

For the experiment, we have defined groups: three experimental (E) and control (C). The groups were selected according to the principle of equal initial data, taking into account the number of students in each group and the results obtained to determine the level of mathematics competence of a future oil and gas engineer.

As a result of pairwise comparison of groups, it turned out that \( \chi^2_{\text{exp}} < \chi^2_{\text{crit}} \) in all groups, i.e. the null hypothesis was confirmed at a significance level of \( p = 0.05 \), corresponding to a 5% level of discrepancy between the experimental data and the tabulated data. And at this stage of the experimental work, the levels of formation of mathematical competence among students of the control and experimental groups do not statistically differ and are suitable for research, which was required to be proved.

The task of the formative stage of the experiment was to implement pedagogical conditions that would increase the effectiveness of the process being implemented. In the experimental groups, changes were made to the educational process in accordance with the model and the proposed pedagogical conditions: in the E1 group, a combination of the 1st and 2nd pedagogical conditions was implemented (organization of training through the introduction of modular educational technology; strengthening the practical orientation of the studied process by applying professionally oriented mathematical problems); in group E2 - a combination of the 2nd and 3rd pedagogical conditions (strengthening the practical orientation of the process under study through the use of professionally oriented mathematical tasks; the use of pedagogical monitoring and self-monitoring to obtain objective information about the effectiveness of the process being carried out and its operational correction); in group E3 the totality of all pedagogical conditions determined by the hypothesis was tested. In group C, training was carried out with the implementation of the model without the identified pedagogical conditions.

The implementation of the first pedagogical condition for organizing training was carried out in experimental groups through the introduction of modular educational technology. The use of this learning technology provided a purposeful orientation of the educational process towards professionalism and competence.

In our work we used modular programs of cognitive and operational type. The realization of cognitive goals was provided by the theoretical content of the educational material. The informational material of the modules was formed according to the epistemological criterion, that is, around the basic concepts and methods of the course “Higher Mathematics”. We used modular programs of a cognitive type in order to form a system of fundamental knowledge of students. Modular programs of the operational type provided the practical part of the educational content and formed skills (to build mathematical models, communicative, algorithmic, functional, geometric and stochastic) in students.

A module is a target functional unit that combines educational content and technology for mastering it. A module is a certain artificial educational environment, which reflects the content, procedural and effective and organizational and managerial aspects of pedagogical tools necessary for solving the assigned tasks. All the developed modules consisted of the following blocks: informational, performance, methodological, control. The knowledge system was formed by the content of the information block, which included theoretical information, illustrated material, additional literary sources, reference books, scientific publications. In the training module, we included an executive block containing laboratory, practical work, tasks of different levels of complexity, questions on the material covered, preparation of reports. We introduced a control block to determine the level of knowledge and skills formation, it contained input control theoretical tests, intermediate control tests, current control for
diagnosing the assimilation of the module's learning elements, task cards of varying degrees of complexity, final control tests. The methodological block, together with the controlling block, represented a system for managing the interaction between the teacher and the student in the process of studying the module. The use of such modules served not only as a means of developing and systematizing the necessary mathematical knowledge, but also as a convenient tool for checking their formation.

When developing educational-thematic modules, we used various forms of organizing training: traditional and non-traditional lectures (with planned errors, with current control, with visualization), laboratory and practical classes, colloquia, mini-tests, and additionally included the participation of students in scientific conferences, round tables, blitz games, press conferences.

The use of modular technology during the formative stage of the experiment contributed to the formation of the epistemological component of the mathematical competence of the future oil and gas engineer.

The second pedagogical condition for strengthening the practical orientation of the process under study was realized through the use of professionally oriented mathematical problems.

We proposed a classification of professionally oriented mathematical problems within the framework of the main mathematical sections that contribute to the formation of:
- the ability to build mathematical models (incomplete tasks with missing data; tasks with dynamic forecasting; tasks involving obtaining data using a simple experiment);
- communication skills (tasks for reading information from mathematical language);
- algorithmic skills (tasks with predictable results; tasks with analysis of the received answer);
- functional skills (tasks for building and reading function graphs; tasks of transition to the analytical form of assigning a function; tasks for functional dependence);
- geometric skills (tasks for constructing figures on a plane and space; tasks for finding the numerical characteristics of geometric figures);
- stochastic skills (tasks for analyzing the situation; tasks for analyzing the answer received; tasks for assessing the reliability of the answer received; tasks related to the general theory of experiment).

At the same time, the practical activity on the formation of mathematical competence included providing the future engineer with all the selected skills in a complex.

For the main sections of mathematics, we have developed a complex of professionally oriented tasks, reflecting the most significant processes, phenomena, concepts of the technical sphere. The selection and composition of tasks were determined by the learning objectives, which were focused on the formation of mathematical competence. Solving these problems of various levels of complexity, students operated on mathematical knowledge and skills, acquired the ability to analyze situations.

Thus, the use of professionally oriented mathematical problems made it possible to strengthen the practical orientation of the process under study and increase the significance of the acquired skills for future professional activities.

The implementation of the third pedagogical condition made it possible not only to obtain reliable and complete information about the level of students' mathematical competence, but also to identify ways to achieve more effective work results. In addition, monitoring ensured the implementation of feedback between the result and the goal, as well as the adjustment of the process of forming mathematical competence. But if in the control group only pedagogical monitoring was used, then in the experimental groups self-monitoring was also carried out, which allowed students to correct their behavior, set certain goals, and predict the results of further work.

In the course of the formation of mathematical competence for our research, the system of monitoring and evaluating students' achievements was of great importance. One of the forms of this system was rating. A positive feature of the rating system was that, by differentiated assessment of one or another side of a student's activity with a certain number of points, a timely motivational influence on the necessary side of a student's work was provided.

However, the rating control system does not exhaust all forms of control we use. To increase the level of the motivational component of mathematical competence we used game forms of control (blitz game, press conference, the game "Journey to the Queen of Sciences").

The inner world of a person cannot be measured by any device, however, both teachers and students themselves have to constantly evaluate their activities. We believe that in any pedagogical research there is a share of the researcher's subjectivity, but the implementation of pedagogical monitoring and self-monitoring in the course of the process of forming mathematical competence made it possible to minimize subjectivity in assessing its results.

At the generalizing stage of the experiment, to assess the changes that occurred during the implementation of the structural-meaningful model and pedagogical conditions during the process under study, the same research methods and diagnostic techniques were used as at the first stage of the experiment. After assessing the level of formation of the components of the mathematical competence of a future oil and gas engineer, we revealed its significant growth in the experimental groups at two levels (high, medium). In the course of the quantitative analysis, it was noted that the number of students with a low level of mathematical competence in the E3 group decreased
significantly - from 55.9% to 8.8%, where a complex of pedagogical conditions was applied, while in the K group - only from 61.8% to 35.3%. The number of students with a high level of mathematical competence in E3 increased from 14.7% to 44.1%, and in group K - from 14.7% to 20.6%. E1 - 61.8%, E2 - 47.1%, E3 - 47.1% and 44.1% of students of group K.

As a result of pairwise comparison of the groups, it turned out that \( \chi^2_{\text{OER}} > \chi^2_{\text{SPRT}} \) (at a level of statistical significance \( p = 0.05 \), corresponding to a 5% level of discrepancy between experimental data and tabulated data) in all groups, i.e. an alternative hypothesis was confirmed at the final stage of the experiment, the levels of mathematics competence formation among students in the control and experimental groups are statistically different.

The data in Table 1 confirm that each pedagogical condition gives a positive result. But in group E3, the value of Pearson’s \( \chi^2 \) test (\( \chi^2_{\text{OER}} = 8.342 \), for \( p = 0.05 \)) is higher than in other groups and more \( \chi^2_{\text{SPRT}} \). This allows us to assert that such an increase occurred under the influence of a combination of the pedagogical conditions we identified.

**Table 1**: Comparative results of changes in the levels of formation mathematical competence of students in the process of studying the course “Higher Mathematics” at the initial and final stages experimental work (%)

<table>
<thead>
<tr>
<th>Group</th>
<th>Level</th>
<th>Value ( \chi^2_{\text{OER}} )</th>
<th>Value ( \chi^2_{\text{SPRT}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start</td>
<td>End</td>
<td>Start</td>
</tr>
<tr>
<td>K</td>
<td>61.8</td>
<td>35.3</td>
<td>23.5</td>
</tr>
<tr>
<td>E1</td>
<td>70.6</td>
<td>8.8</td>
<td>14.7</td>
</tr>
<tr>
<td>E2</td>
<td>67.6</td>
<td>11.8</td>
<td>14.7</td>
</tr>
<tr>
<td>E3</td>
<td>55.9</td>
<td>8.8</td>
<td>29.4</td>
</tr>
</tbody>
</table>

Note: OER - experimental work.

Thus, the number of students with a high level of mathematics competence has increased, for whom possession of meaningful, complete theoretical knowledge, the improvement of the culture of thinking, the ability to acquire knowledge on their own and use it in practical and laboratory classes in solving theoretical and engineering-practical problems is characteristic. A steady interest in future professional activities has appeared, students are aware of the practical and theoretical importance of mathematical knowledge, perceive them as personally significant.

At the end of the 6th semester, students of the control and experimental groups participated in the Internet exam in the field of vocational education (FEPO), which was conducted in the form of computer testing (44 tasks). We put forward a hypothesis, which consisted in the fact that there is a connection between the obtained test results and estimates of the indicators of the level of mathematical competence among students. The hypothesis was tested using the correlation coefficient, which showed a close relationship between the assessment of indicators of the level of mathematical competence and the results of the final testing (r = 0.94).

In the methodological literature, it is generally accepted that a student has coped with the testing and has a high level of development if he correctly completed at least 80% of the tasks (for our case, these are 35 - 44 tasks), average - if at least 50%, but less than 80 % (in our case, 22 - 34 tasks) and low - if less than 50% (less than 22 tasks). From table 2 shows that the test results in the experimental groups were better than in the control. Consequently, the results obtained in the course of the formative experiment are not accidental, which indicates the correctness of the choice of pedagogical conditions.

**Table 2**: Internet-exam results

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of students (X ( \geq 80 % ))</th>
<th>Number of students (50% ( \leq X \leq 80 % ))</th>
<th>Number of students (X ( &lt; 50 % ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>6</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>E1</td>
<td>11</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>E2</td>
<td>12</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>E3</td>
<td>14</td>
<td>17</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: X is the number of correctly completed tasks in testing.
4. Conclusions

In conclusion, on the basis of the generalization of the theoretical provisions, the results of experimental work, we formulated the main conclusions, outlined the ways for further research:

1. Despite the fact that the theory and practice of higher education pedagogy has accumulated a certain experience in the formation of students' mathematical competence, the issue of the formation of this competence in future oil and gas engineers in vocational training remains poorly studied.

2. In the course of the theoretical study, the concept of "mathematical competence of a future oil and gas engineer" was clarified, which we consider as a unity of epistemological, praxeological, axiological components that provide him with the ability to solve theoretical and engineering-practical problems that are significant in the professional activities of a modern specialist in engineering and technical profile.

3. A structural-meaningful model of the formation of mathematical competence of a future engineer has been developed, based on the competence-based approach, which is an integral complex of interrelated elements that form a unity, and includes target, meaningful, activity-procedural, performance-evaluative components.

4. Defined, substantiated and experimentally tested a set of pedagogical conditions for the successful implementation of the structural-content model, which includes: a) organization of training through the introduction of modular educational technology of training; b) strengthening the practical orientation of the process under study through the use of professionally oriented mathematical problems; c) the use of pedagogical monitoring and self-monitoring to obtain objective information about the effectiveness of the ongoing process and its operational correction.

In general, the results of the experimental work confirm the assumption that the formation of the mathematical competence of a future engineer is carried out more efficiently if it is implemented on the basis of a structural-content model and taking into account the selected pedagogical conditions. The analysis of the obtained quantitative and qualitative results of the experimental work showed that the hypothesis put forward has found its experimental confirmation - the goal of the study has been achieved.

The study does not claim to be a complete consideration of all aspects of the process under study. In the course of the work, new tasks were identified that needed to be solved. Further research can be continued in the following areas: development of alternative methods for diagnosing the level of formation of the components of mathematical competence and curricula for teaching mathematics through the introduction of new educational technologies.

References