Elective courses for training the mathematics teachers to realise STEM approach

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Abstract. The article presents the results of research in the field of university training of mathematics teachers aimed at realising STEM education at school and other educational organisations. The authors identified 1) insufficient readiness of school teachers to implement STEM training, and 2) lack of professional mathematics teachers having special qualification in this area. Based on Russian and foreign experience, the authors propose to use the potential of the elective courses for purposeful preparation of future mathematics teachers to implement STEM training. The approach to designing the content and technological components of such a course rests on the principles of practical orientation, multidisciplinarity, professional orientation and the application of a regional context. The course consists of theoretical and practical modules, which make it possible to integrate the potential of all STEM components in the professional training of teachers and to master the basics of STEM implementation.

1. Introduction
The rapid transformation of society and the economy highlights the need to spread and develop technical and engineering education, which is embodied in the ideas, methods and technologies of STEM (Science, Technology, Engineering, Mathematics) or STEAM (Science, Technology, Engineering, Art, Mathematics) approaches. However, many countries cannot ensure high quality of education for students in the exact sciences, which makes it difficult to train modern scientific and engineering personnel in the 21st century. Many scientists and teachers in Russia and abroad are looking for solutions to this problem in the context of teaching STEM. This training is based on the ideas of interdisciplinary links and applied orientation.

At present, both the didactic potential of STEM education and the specifics of its implementation are being actively explored. The following works examine STEM-learning as a pedagogical phenomenon affecting the improvement of the quality of education in science, mathematics and computer science as regards students’ readiness to use integrated knowledge of these disciplines in solving practical and engineering problems: A.N. Bogdanova [1], A. E. Strizhak, I.A. Slipukhina, N.I. Polikhun and I.S. Chernetsky [2], T.R. Kelley and J.G. Knowles [3], L.S. Nadelson and A.L. Seifert [4], A. Leung [5], Kuen-Yi Lin, Hsien-Sheng Hsiao, P. J. Williams and Yu-Han Chen [6], etc.
Particular attention in the STEM aspect is paid to the specifics of each discipline, including mathematics. Mathematics occupies a special place in STEM training, as its methods are in urgent demand for modern projects in various fields. On the other hand, a number of authors have found that one of the most effective ways to improve the quality of students’ mathematical training is their participation in finding mathematical solutions to real problems [3], [7], [8].

The available results of STEM education confirm its effectiveness in improving the quality of students’ training both in STEM disciplines and applying STEM methods to various research tasks, including engineering ones. Nevertheless, an analysis of educational practice has shown that most teachers are not ready to introduce STEM training. The objective difficulties of teachers, including teachers of mathematics, and the problems which they faced in implementing STEM training were studied in the publications of T.I. Anisimova, F.M. Sabirova and O.V. Shatunova [9], O.V. Shatunova and S.V. Ivanov [10], J. Utley, T. Ivey, R. Hammad and K. High [11], T.R. Kelley and J.G. Knowles [3], A. Struyf, H. De Loof, J. Boeve-de Pauw and P. Van [12]. J.H.L. Koh [13], D.J. Shernoff, S. Sinha, D.M. Bressler and L. Ginsburg [14], L. Shikerina, A. Bagachuk and Yu. Bocharova [15], etc.

An analysis of works in this area shows that there are positive experiences in preparing teachers for STEM training, but more often this experience is not a constituent part of the formal training of future teachers, particularly mathematics teachers. As a rule, the necessary skills are acquired by teachers who are already employed during their retraining (professional development). For example, J. Radloff and S. Guzey’s study emphasises the problem of preparing a teacher for STEM education in the USA, such a teacher who would be qualified in STEM content, instructions and educational technology. The authors propose the idea of visualising STEM training for teachers in combination with STEM text support and the basic conceptual provisions [16]. J. Utley, T. Ivey, R. Hammad and K. High believe it expedient to brief primary school teachers during their professional development on the specifics of engineering activities. According to the authors, this will increase teachers’ confidence in teaching engineering concepts to their students [11]. D.J. Shernoff, S. Sinha, D.M. Bressler and L. Ginsburg admit that in order to be successful in STEM training, teachers must undergo comprehensive integrated training as an essential component of intensive retraining courses. The conceptual basis for such training in the format of STEM disciplines should include project-based learning, personalised pedagogy and twenty-first century skills transfer. It is stressed that the teacher should be a specialist not in a single discipline, but in all of the disciplines that make up the STEM block. The priority goal is to achieve the qualification “Teacher of STEM” [14]. The experience of university training of future teachers for STEM training is less studied. In this regard, the publications of S.G. Grigoriev, A.R. Sadykova and M.V. Kurnosenko [17], N.Y. Zubenko and E.I. Sukhova [18] are of special importance. The authors present the methodical experience of introducing STEM-technologies in the process of training Master students in the field of “Pedagogical Education”, the profile “Mechatronics, robotics and electronics in education”, at the Moscow City Pedagogical University. Their work also describes the input of bachelors who major in the “Pedagogical Education” in the creation of STEM-projects for preschool children. Also, the Malaysian education system is no stranger to realising teacher training through a special methodological course, namely the experience of the School of Pedagogical Research, which has taken the initiative to train future teachers in the “Methods of teaching chemistry” course for STEM education [19].

Thus, at the level of educational theory and practice, there is a problem of finding effective methods of forming teacher readiness for STEM training, which can be successfully solved in the process of preparing the future mathematics teacher at the university.

This article explores the following issues:

- the experience and readiness of general school teachers to realise STEM training;
- the content and technological components of an elective course within university training of teachers of mathematics for the implementation of STEM-learning.
The aim of the study is to develop approaches to the design of the content and technological components of an elective course aimed at preparing future teachers of mathematics for the implementation of STEM education.

2. Materials and methods
The initial stage of the study included an analysis of the scientific literature on the problem in question, and also summarising and systemising the results of scientific research. The use of these analytical methods allowed us to identify the main directions in the implementation of STEM-learning in the general education school, the specifics of the design and organisation of the educational process following the logic of the STEM approach, which must be mastered by future mathematics teachers.

The use of empirical methods (survey, observation) helped to collect relevant information on the experience and readiness of teachers in general education schools to implement STEM training. The opinion poll encompassed 200 teachers of secondary schools in Krasnoyarsk. The survey results demonstrated that 92% of teachers have a good understanding of STEM training and positive attitude towards it; 11% use it in the process of subject training; 85% would like to use it, but do not have the necessary methodological support. In addition, 78% of the respondents admitted that they have insufficient subject and methodological training in the implementation of STEM education and that they need to fill in the professional gaps in this area. Trying to establish links between mathematics and other disciplines, teachers concentrate on subject content while missing out on recurrent concepts and real-life applications in mathematics. Instead, it is more appropriate to implement an integrated approach, to search for connections between STEM disciplines. As for the subject content, it is advisable to offer a corresponding context for the application of the methods being studied. The results of the study provided the basis for developing an elective course targeted at preparing future mathematics teachers for the implementation of the STEM approach in the educational process. The application of pedagogical design at the final stage of the study enabled us to develop the content and technological components of the elective course, taking into account the specifics of the STEM approach.

3. Results and discussion
In the process of theoretical research there were specified main directions in the implementation of STEM-learning in the conditions of the general education school, i.e. formation and development of engineering thinking of students, acquisition of experience in educational and research activities, acquaintance with new technologies in the field of natural sciences and possibilities of their application for solving real problems, mastering mathematics as a tool for learning the surrounding reality. These areas are reflected in the content of the developed elective course.

The personnel in the modern school are predominantly bachelors in pedagogical education. Hence, their preparation for the implementation of STEM training appears topical. This task can be realised in the following forms: 1) specialized training in the field of “Pedagogical Education” (in this case the graduate will have the qualification of “Teacher of STEM”); 2) preparation for an additional educational programme during the mastering of the basic professional educational programme; 3) training in the conditions of special elective courses from the variative part of the curriculum during mastering the basic professional educational programme.

The main result of the work performed was the development of an approach to the design of the content and technological components of the course “Support of STEM-projects of students”, the realisation of which is planned within the framework of the variative module of the curriculum for the direction “Pedagogical Education”, profile “Mathematics”. The main objective of the course is to teach a future mathematics teacher how to organise and support STEM projects for students. The foremost tasks of the course are developing students’ ability to identify current problems in the area of students’ residence; developing students’ ability to obtain (find) knowledge in mathematics, physics and IT, which is necessary to solve the problem; providing conditions for students to gain experience in the systematic use of knowledge in mathematics, physics and IT for solving problems; providing conditions for
students to gain experience in assisting schoolchildren implementing STEM-projects based on the systematic use of knowledge in mathematics, physics and IT.

The following principles form the basis of the course content and implementation: practical orientation (immersion in solving real life problems); multidisciplinarity (creating conditions for gaining experience in using the tools of various scientific fields); professional orientation (creating conditions for getting experience in professional and pedagogical activities); availability of regional context (studying the main issues through the prism of their usefulness for solving acute regional problems).

The content of the course includes two main modules: “STEM Training Basics” and “STEM Internship”, which differ in their intended purpose.

The module “STEM Training Basics” gives students the main features of the STEM approach in education; contemporary STEM issues of the 21st century; integrants of forming engineering thinking; achievements of modern science and technology and possibilities of their application; applied mathematics; details of creation and development of students’ research activities. The study of these issues involves solving cases from real life: space rocket launch, bridge construction, oil refining, robot assembly, etc. The analysis of these cases helps students better understand the application of theoretical knowledge in real conditions and the practical functioning of mathematical knowledge.

Here is an example of the practice-oriented task offered to students in the course.

«A cylindrical-shaped frame pool is going to be installed in the room. Estimate whether the height of the threshold of 9 cm will prevent the adjacent rooms from being flooded in case the pool walls break through. Consider the following circumstances when calculating:

- the area of the room in which the pool is to be installed is 24 m²;
- the height of the pool is 1.4 m;
- the diameter of the pool bottom is equal to 3 m;
- when the pool is filled with water, the distance between the water level and the upper edge is 20 cm.

Calculate the lowest threshold height possible under given conditions in a room with a swimming pool».

For group work, students are offered integrated tasks of project and research nature, in the course of solving which inter-subject links between mathematics, physics and computer science are consolidated. During search and research process, students develop and update soft and hard skills. An example of one of these tasks is shown below (figure 1).

The “STEM-Internship” module implies STEM-immersion and plunge into profession for students. STEM-immersion means the involvement of students in the development of STEM projects as the main subjects of educational and cognitive activities. It is based on effective strategies for integrating applied mathematical research and pedagogical technologies. The module is focused on the creation and development of their engineering style of thinking (ability to set a goal, taking into account available resources; opportunity to choose the best methods and means to achieve the goal, to plan the sequence of actions; competency in building and choosing the most reasonable type of model depending on the task at hand; capability to transform, evaluate, implement, etc.) and research style of thinking (ability to go beyond the available algorithms and samples, to determine the novelty of the task at hand, etc.). This programme will allow them to master what they will have to teach themselves, as at present students at teacher training institutions have no experience in such activities. When organising this module, preference should be given to different forms of teamwork. In addition, in mastering this module, special emphasis shall be on the specifics of working with the modern generation of students – Generation Z. Students gain experience in designing and implementing an educational process that makes allowance for the specifics of the cognitive sphere of centennials and their personal qualities [20]. The module is realised as part of the pedagogical internship on the basis of engineering classes of general secondary
schools in the region, and also in a technopark, a centre for youth innovative creativity and other organizations of additional education.

| Regional context: | Task: |
|------------------|-------|
| One of the gravest problems in the Krasnoyarsk Krai is forest fires. Every year, big fires break out in hard-to-reach and remote areas of the forest. Amphibious fire-fighting aircraft, in particular Be-200 Altair, are used to extinguish forest fires in such areas. It is problematic to use such aircraft in the Krasnoyarsk Krai, as there is no suitable airfield for Be-200 in the northern areas of the Krai. | - to determine the most optimal location in the Krasnoyarsk Krai for the construction of an airfield and describe its technical characteristics; - to build a mathematical model of amphibious aircraft’s airway; - to examine the horizontal and vertical stability of the aircraft in turbulent conditions; - to visualise on a computer the flight model of amphibious aircraft (taking into account its technical characteristics) from the proposed aerodrome. |

| Formed Soft / Hard Skills: | Inter-subject connections: |
|---------------------------|---------------------------|
| - understanding the importance of the skills developed, prowess in aero-engineering; - search for the information required and usage of such information to perform a quasi-professional task effectively; - use of ICT, mathematical methods for solving tasks; - team-working, building constructive interaction with colleagues. | Mathematics, computer science, physics. |

**Figure 1.** Example of an integrated task for a group work.

Professional immersion necessitates organizing joint case studies with schoolchildren of general secondary schools, as well as making students supervise real STEM projects of students. Joint case studies will allow students to understand pedagogical strategies in solving STEM problems, develop individual tactics of interaction with students, which will ensure effective problem solving and adjusting ineffective strategies [21].

A promising approach to the selection of project themes is extrapolating the current STEM issues of the 21st century to the conditions of regional development. These can be projects that require an integrated approach, which are related to the search for new solutions for the design of an accessible and convenient urban environment, a healthy ecosystem, energy-saving technologies, recycling of waste and transition to alternative energy sources, etc. The proposed solutions must contain not only original ideas, but also arguments and proofs for their viability and feasibility in actual conditions.

The suggested approach to designing the content and technological components of the course sets out a certain framework that can be successfully transformed and implemented also in the process of training bachelors majoring in other directions.

4. Conclusions
The described approach is supposed to change the quality of certain mathematics lessons in a modern general education school. The educational process has to initiate research, incorporate design methods and techniques, thus ensuring that the idoneous education of school leavers, which would allow them to be successful in today’s world and to get into the talent pool for an innovative breakthrough in high technology. On the other hand, targeted training of a mathematics teacher at university for the further implementation of STEM approach at school will help level out shortages of professional teachers at a modern Russian school in the area of preparing students for STEM projects. The course can also be
introduced in the system of retraining (professional development) of teachers and engineers. The prospects for advance research may include the design of similar integrated courses for teachers in other subject areas, as well as the search for new technologies, forms and means of course implementation for training a future teacher.

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