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STEM vs STEAM: Developing a New Teacher

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ABSTRACT
Interaction and interpenetration of scientific fields promote the concept of transdisciplinarity to play a key role in education. One of the most efficient practices of its implementation is believed to be STEM/STEAM-education which unites Science, Technology, Engineering, Arts, Mathematics into the holistic educational process. The purpose of this article is to review international and national research literature devoted to the study of the methodological side of STEM and STEAM education. The authors analyze the background of the appearance and development, current trends, the position and the role of the student and the teacher, external and internal factors that hinder or contribute to the successful introduction of STEM and STEAM education into the educational process in different countries. Based on the conducted analysis an innovative project STEAMTeach is presented as a new educational model of professional development of pre-service teachers.
Keywords: *STEM and STEAM education, transdisciplinarity, professional development of pre-service teachers, project-based teaching*

1. INTRODUCTION

Nowadays, the concepts of interdisciplinarity and metasubject approach play a key role in education. Integration takes place at the levels of disciplines, forms of education, methods of organizing educational activities, forms of interaction among participants in the educational process. These trends are determined by a range of political factors such as the state policy to strengthen the role of engineering education in the world, changes in the state educational policy which are aimed at accomplishing complete transformation from subject- and knowledge-centric teaching to a competence-based approach, the introduction of new federal educational standards that impose requirements for the development of 'metasubject, universal learning activities (cognitive, regulatory and communicative)' [22; 34]; socioeconomic factors such as the fourth industrial revolution, globalization, informatization of society spheres, strengthening of the role of the hyperbolic information flow, automatization of the work process, a shortage of engineering and high-tech specialists [20; 26; 28]; educational factors such as low levels of reading, science and mathematical literacy of Russian graduates in comparison with the results of American and European graduates, that showed the narrowness of students' knowledge and the lack of understanding interconnections and interaction processes in the real world among students, high rate of information "obsolescence", low interest in professional involvement in technical fields, the need for developing a new type of specialists with competencies to allow them to remain in demand in the future when brand new professions appear [1; 14; 26]. These trends show that in order to maintain a leading position in the world economy, the state educational policy must promote a strategy to advance innovations when training a specialist of the 21st century. In the context of education it implies training teachers of a new type applying the concepts of inter- and metadisciplinarity as leading principles in the educational process.

Studies of the problems of integration, interconnection and universality of knowledge in the context of such educational concepts as "interdisciplinary connections", "interdisciplinarity", "interdisciplinary approach", "interdisciplinary integration" were raised in the context of the problem of scientific comprehension of the universality of the world and the personality in terms of interaction and interpenetration of sciences. In order to understand the educational processes in the global aspect, the trend of globalization becomes an important phenomenon to examine as it influences all spheres of society. In the social context, it led to the erosion of the territoriality of global and de-territorial sociality, the internationalization of society, the development of transnational mass culture, intensive mass migration and the formation of multicultural communities and multinational cooperation [5; 9; 19]. In the cultural context, a process of consolidation of transnational culture took place and led to the formation of hybrids of cultures and introduction of the concept of transculturalism promoting the total freedom from original culture and creating a new position of "outsidedness" [4; 6; 10; 27; 32]. The interest in revealing not specific phenomena and concepts that are in the field of study of certain sciences, but general scientific and general cultural ones - universals - is conditioned by the universality and accessibility of information media spheres, tendencies to comprehend the universal synthesis of knowledge, humanization and humanitarization of education, the phenomenon of self-organization of complex systems, and the culturally conditioned nature of education [3; 11; 13; 30]. The concepts of technocratic and scientific determinism, economic, political and cultural globalism are set opposed to the concepts of humanistic and social universalism,

synergetics as self-organization of complex systems, the dialogue of cultures and dialogue-polylogic learning, scientific principles of relativity, complementarity, uncertainty, instability, autonomy, eclecticism, system pluralism, co-evolution, nonlinearity, continuity, pragmatism, individualization of education, which should underlie the basis of a new paradigm of science and education [6; 7; 15; 21; 33]. This paradigm is designed to integrate knowledge overcoming its standardization and reduction to uniformity through emphasis on the ontological principles of the leading science, the so-called existence of "unity in diversity" (im pluribus unum), which is currently most successfully accomplished in the concept of transdisciplinarity [6; 42; 44].

2. BACKGROUND

One of the most successful practices of the concept of transdisciplinarity is STEM/STEAM education. STEM includes four majors that play a key role in technical and economic development: S – Science, T – Technology, E – Engineering, M – Mathematics. In STEAM A-component is added to the above mentioned disciplines as Art.

To review modern research literature and study the methodological issues we analyzed 170 articles by Russian, American, European and Asian researchers. The selection was carried out from leading international scientific journals such as the International Journal of STEM Education, International Journal of Educational Development, International Journal of Science Education, European Journal of STEM Education, Journal of Research in Science Teaching and others, as well as Russian journals included in national citation index bases and rating systems such as RSCI or HAC and cited in other journals. Figure 1 shows a graph examining the number of articles devoted to the study of STEM or STEAM issues that have been published over the past 5 years and earlier (see Figure: 1).

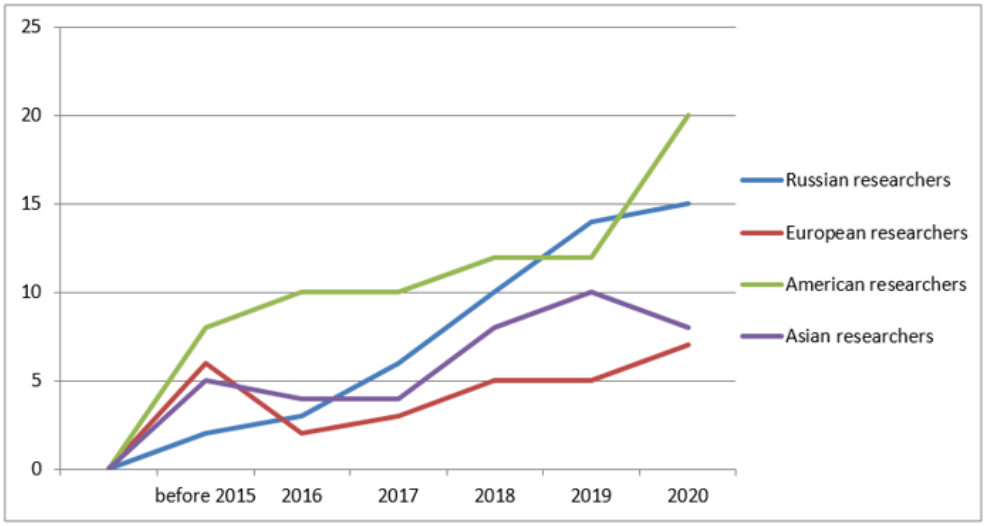

Figure 1 Number of publications using STEM/STEAM as a keyword

Using the keywords STEM and STEAM when searching, a tendency for the growing number of articles over the past 5 years both in international and national journals has been revealed. In our analysis, it was educed that both concepts are interpreted differently as "conceptual ideas", "practices", "approaches", "type of education", "technology"; however, most interpretations describe STEM and STEAM as a synthetic integration of disciplines into the educational process, in which 'the whole is greater than the sum' [1; 2; 8; 20; 26; 36; 42]. Most researchers emphasize practice-oriented approach, i.e. the focus on the context of application in real world and the continuity of education from preschool to higher education, proactive independence, and self-management, and also see the system-and-activity-based approach and project-based teaching as the foundation of a new type of education [2, p.328].

The A-art component (creativity) has attracted active research interest only after 2018, until that time, research was directed towards technical (Russian, Asian and American studies) or natural science issues (European studies). STEM is the predecessor to STEAM and originated in the 20th century in the United States. Many scientists believe that STEM should be viewed in the context of geopolitical, nationalistic and militaristic discourse, since the precondition for its emergence in the United States was the launch of the Soviet satellite and the "arms race", which is why STEM research and development are still characterized in some sources as Americentrism [23; 24; 42]. It is important to note that the emergence of STEM in China was also influenced by the Soviet Union, as they also took the course to researching and developing industry and the military forces for their protection under a centralized government [49; from 84]. In Russia, the need

for STEM development was determined by the influence of entrepreneurship and innovation areas facing a shortage of STEM-literate technicians who would be able to work in the engineering areas in high-tech industries [1; 14; 23]. The appearance of STEAM education was presupposed by the experience of STEM education implementation that initially relied on technical specialization which being combined with the humanitarian component was directed to synthesize knowledge, sciences, art and technology as a future basis for interdisciplinary educational projects [2; 20].

Analyzing the problems raised by American scientists, it was noticed that the problem of equal rights in education is being raised, and the issues of gender, nationality, race and socioeconomic status inequality in getting education and choosing a technical specialization have been discussed. Due to it a lot of researchers see STEM and STEAM as a resource for providing equal educational opportunities for all students [37; 45; 47; 48; 50; 51; 53]. European journals also pay attention to this issue with their main focus being students with special educational needs and the possibilities of introducing STEM and STEAM into inclusive education [43; 47; 50].

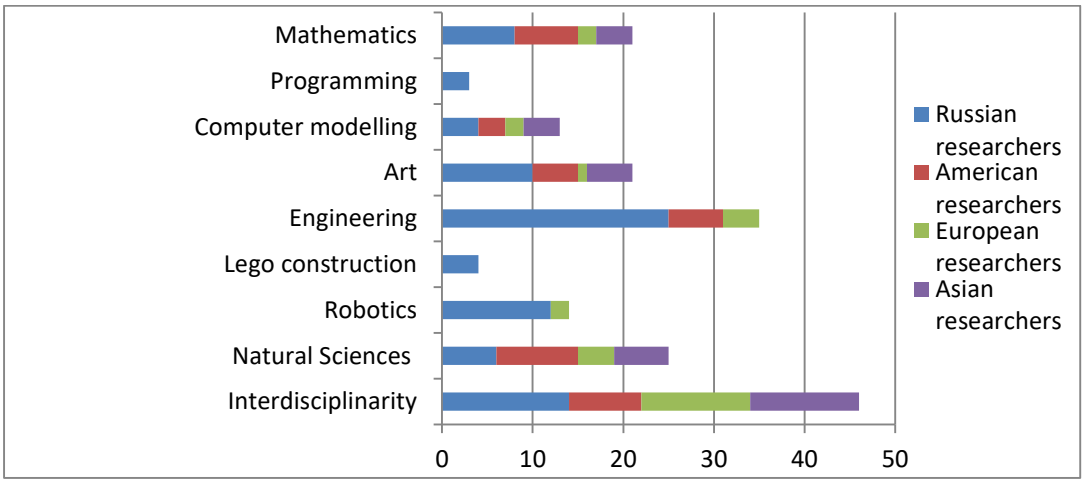

Figure 2 Areas of STEM and STEAM disciplines in the focus of Russian, American, European, and Asian researchers

Researchers from different countries prioritize STEM and STEAM subject areas differently (see Figure 2). Russian scientists place the greatest emphasis on the development of engineering, robotics, and mathematics. This is due to the fact that the need for scientific and engineering workforce continues to grow as high-tech industry advances, and new jobs the growth of which exceeds the number of specialists are being introduced [14; 23].

While Russian studies focus on a particular discipline, American and European studies focus more on issues of interdisciplinarity and project-based teaching within the framework of the K-12 system. They raise questions about the liberalization of boundaries among disciplines viewing a discipline as an individualization of multiple scientific fields, and STEM and STEAM are designed to prepare students for their recognition in the real world, where everything is interconnected and represents a single whole [42].

Asian studies address the role of language learning in STEM and STEAM. Some researchers adhere to the point of view that this type of education pays little attention to language literacy, others believe that technical disciplines are replacing the humanitarian, and transdisciplinarity is not fully achieved between these two subject areas [17; 41].

Asian researchers have identified the concept of "scientific literacy" [34; 39]. To overcome the lack of scientific and technical personnel and attract young people to these specializations, a new motto in education has been proclaimed: "Science and technology are the leading force, talent and knowledge must be respected". Therefore, the state subsidizes all areas of scientific research, and education seeks to develop specialists for scientific breakthrough [49].

It has been noticed that in many studies such concepts as STEM/STEAM literacy, STEM/STEAM thinking, STEM/STEAM skills, STEM/STEAM teacher appear in different contexts, which leads to the suggestion that STEM/STEAM is a universal education for the development of an up-to-date specialist.

Currently STEM is associated with the utility and values of instrumentalism, which has the main goal of maintaining economic growth and productivity [1; 23; 42]. The need for aesthetic expansion and diversification of education by increasing complexity of discipline evaluation and reorienting from mainstream discourse has revealed the necessity for disciplinary and spatial expansion, which is designed to overcome the limitations of STEM and STEAM [40; 42]. The involvement of multi-skilled specialists, the application of knowledge and practices from different scientific fields, the determination of STEM and STEAM outside the relationship of sciences, the advance of transdisciplinarity, the inclusion of synergetic and reflexive teacher-student relationships should become the basis for a new model of education [41]. Focusing on aesthetic values

by organizing art spaces for students to work together with representatives of the economy, business, and industry, creating interschool and interuniversity platforms and a network of research and educational centers will help to overcome instrumentalism and raise the importance of human capital.

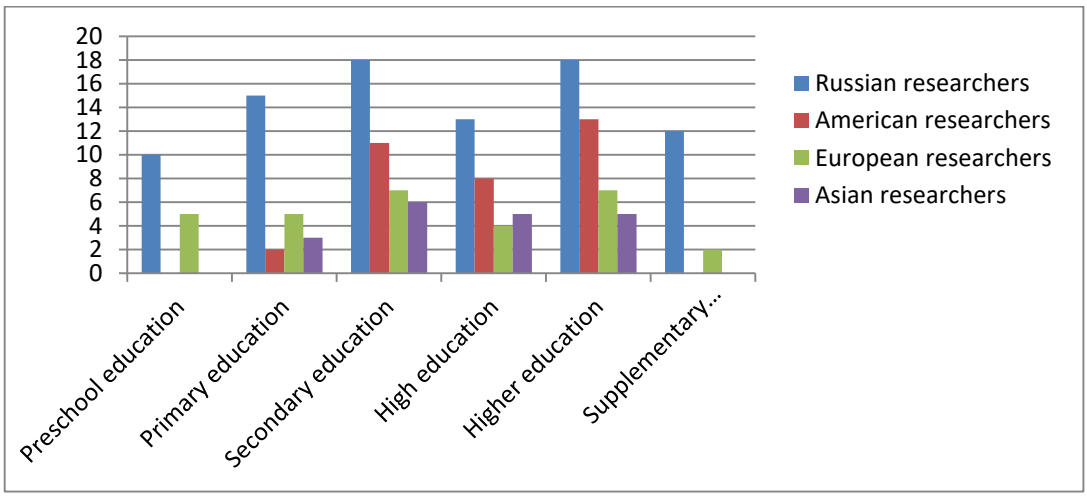

Figure 3 Levels of STEM and STEAM implementation at different levels of education

Based on Figure 3, we have identified the success rate of STEM and STEAM implementation at different levels of education. In Russia, STEM and STEAM are actively developed in the framework of extracurricular, primary and secondary education, while STEM and STEAM in high and higher education have begun to gain popularity in recent years [1; 2; 3; 12; 18; 20; 25; 29; 31; 35]. Extracurricular education is promoted by such companies as Intel, Lego, Polymedia, which are interested in providing opportunities for the implementation of innovative projects and support for graduates [14; 17; 36; 46]. American education is regulated at the state level by the introduction of new STEM educational standards in the framework of K-12 system. Also in the United States, a whole system of non-governmental organizations and associations has been created to coordinate activities in promoting STEM education and arousing interest of their main stakeholders, students of high school and higher education, in STEM areas [24].

The position and role of the student in STEM and STEAM is assessed ambiguously. Some scientists are criticized for presenting students as a set of characteristics: gender, race, ethnicity and socioeconomic status, which makes it difficult to take into account their individuality, experience, background and desires and, thus, to frame a proper educational route within STEM and STEAM [42; 48]. Others see students as "entrepreneurs", "generators of capital", "innovators". Many researchers come to the conclusion that the question should not be raised about what to teach, but who to teach. This approach should make STEM and STEAM more oriented to the needs and characteristics of the student and develop a new type of thinking [38]. Experts hold different opinions on which type of thinking should be developed: critical thinking, computer thinking, engineering thinking, project thinking, spatial thinking, highly organized thinking [17; 20; 23; 25; 36; 42].

Asian research focuses not on a certain level of education, but on the search for talents among students of all levels of education and their further support and development [38; 52]. Initially, the state tried to give everyone the same rights and opportunities in education, neglecting the need to highlight the gifted, but nowadays the educational policy aims at overcoming the emerging crisis of talented youth through implementing a talent cultivation model in education which means developing creative and innovative problem-solving skills in students [38].

Particular attention should be paid to the individual potential of students, since cognitive, intrapersonal and interpersonal skills will be the most demanded in the 21st century [16]. All these skills are associated with the personal capital of the individual, their cognitive processes, social activity, values, experience, which require the teacher to be flexible and prepared to go beyond the content of their subject, to anticipate the further development of the student, to develop competencies of the future, the main of which is to learn throughout life and adjust to changing circumstances.

It has been noticed that very little attention is paid to the support and raising awareness of parents and teachers. The position and role of the teacher in STEM and STEAM are considered by researchers in different ways. They become "facilitators", "guides", "leaders", but most researchers admit that today's teachers face a lack of professional competencies for using STEM and STEAM technologies and equipment, a shortage of elaborated curricula, teaching materials, assessment criteria, means of subject integration, limited school space and others [3; 38; 39; 52]. Researchers have identified external and internal factors that contribute or hinder the successful implementation of STEM and STEAM. The external factors include the availability of educational resources and training equipment, support from parents and public organizations, adequate number of

students in a group, and direct collaboration between universities and schools [39; 41; 42]. Among the factors that hinder the successful development of STEM and STEAM are the lack of equipped classes for experimental activities, the time limits of lessons, the lack of advanced training courses for teachers and training manuals for integrated learning, a shortage of training equipment, lack of cooperation among teachers, emphasis on content coverage rather than on its understanding, a low level of digital literacy of students, lack of interdisciplinarity in the curricula which leads to complication in integrating disciplines, unpreparedness of students for a new type of education [38; 39: 40]. Analysis of the above mentioned factors shows that they are all interconnected and arise from each other. For example, the problem of equipment availability is associated with a large number of students in a group and the problem of allocating time to everyone. The lack of motivation and initiative on the part of teachers can be explained by the lack of teaching aids and the inconsistency of curricula and programs with a new type of education, which hinders their cooperation. The researchers note that modern teachers are not ready for the transformation to STEM and STEAM, since they were not trained in compliance with this principle. The low level of engineering knowledge, the lack of full implementation of transdisciplinarity in the curricula and in the classroom, the use of ICT to reinforce the content rather than to promote understanding, the insufficient amount of learning space inside and outside the educational institution make it hard to change the established pedagogical approaches and principles [38].

3. RESULTS

The team of the Institute of Education of Immanuel Kant Baltic Federal University (Kaliningrad, Russia) offers an innovative approach – STEAMTeach. This project is aimed at introducing a new educational model for the professional training of pre-service teachers based on a practice-oriented approach which implies the development of educational programs of a new type for STEAM education, the modernization of the assessment system in the Final State Certification, the development of a brand-new model of educational cluster leading to introduction of new educational practices. The implementation of this educational model implies:

– introduction of a number of disciplines focusing on the project activities and phenomenon-based learning ("Ecosystem of project activities at school", "STEAM-practices in a modern school" and others) into the curricula;

– extensive application of case- and project-based methods, TRIZ-based technology, research experiment by teachers;

– development and introduction of a Demonstration Exam based on WorldSkills methods and techniques as a form of Final State Certification of pre-service teachers which implies modeling real educational environment and assessing the compliance of the graduate's competencies with the requirements of standards, employers, international companies;

– creation of a new model of the network educational cluster "STEAM Community" involving the Kindergarten-School-University model of interaction, which implies the organization of a system of professional competitions in terms of teaching, the development and implementation of technologies for pedagogical support of students in the field of engineering, scientific and technical creativity, sustaining of extra-curricular activities in educational institutions by organizing and conducting local festivals of creativity and inventions.

The relevance of our project lies in the fact that the STEAMTeach model ensures the management of the professional development of pre-service teachers by optimizing all available resources (teaching and methodological, pedagogical, human, network, material, etc.) and their orientation towards the introduction of STEAM-technologies in the educational process of teacher training. As a result, a new teacher training model STEAMTeach will be tested for further implementation in pedagogical universities of the Russian Federation. This model is to optimize the content of higher pedagogical education in accordance with federal, professional, and international standards.

4. CONCLUSION

In conclusion, we have illustrated different approaches to representation of STEM and STEAM concepts in national and international research in recent years including the core idea of implementing transdisciplinarity in education. The analysis showed that educational phenomena STEM and STEAM are considered in political, socio-economic, nationalist, militaristic discourses. We found that further research in this area should be devoted to studying the role of the teacher, STEAM orientation of teacher training and developing methodological guidance and aids for service teachers.

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