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STEM-технология: актуальность и возможности дисциплинарной конвергенции в инженерном образовании

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Аннотация. Обстоятельства, в которых оказался мир в последние годы, обнажают ряд проблем в подготовке инженеров и дают системе технологического образования свежие импульсы для соответствующего времени функционирования и эффективного развития. Происходящие сегодня в образовательном пространстве трансформации объясняются, главным образом, еще и тем, что обнаруживаются ресурсы, подпитывающие идею о непрерывном и в то же время направленном на конкретную цель профессиональном инженерном образовании. Дуальность обучения ассоциируется, с одной стороны, с качественной теоретической подготовкой будущих конструкторов, программистов, технологов; с другой, – с формированием у них способности решать практические производственные задачи. Трансдисциплинарность становится ключом и главным вектором развития технологического образования. Появляются подходы в обучении, которые способны воплотить идеи дуальности и трансдисциплинарности в конкретных образовательных программах. В статье обсуждается связь и зависимость названных факторов между собой. Несмотря на ощутимые изменения, инженерное образование по-прежнему не лишено проблем. Целью данной статьи является обсуждение болевых точек и возможностей STEM-подхода. Методологическая основа исследования – рефлексия теоретических взглядов на инженерную экономику, политехническое образование, технологическое предпринимательство, дисциплинарная конвергенция в подготовке инженеров будущего; анализ исследовательской и педагогической практики в сфере технологического образования; интервьюирование экспертов, проведенное в марте 2023 года, с целью обнаружения проблемных зон и перспектив STEM-образования. Результаты показали, что расширению технологического образовательного пространства может способствовать развитие трансдисциплинарных исследований и проектов, конвергентных технологий, опыт решения жизненных проблем силами специалистов из разных профессиональных сообществ.

Ключевые слова: инженерное образование; STEM-подход в образовании; пространство обучения; инновационное инженерное проектирование; трансдисциплинарность; среда обучения; современный образовательный ландшафт

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Original article

STEM-technology: relevance and possibilities of disciplinary convergence in engineering education

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Abstract. The conditions in which the world has found itself in recent years reveal a number of problems in the training of engineers and give the system of technological education fresh impetus for the appropriate time of functioning and effective development. The transformations taking place today in the educational space are mainly explained by the fact that resources are being discovered that feed the idea of continuous and at the same time directed professional engineering and technological education to a specific goal. The duality of training is associated, on the one hand, with the qualitative theoretical training of future designers, programmers, technologists, and, on the other hand, with the cultivation of their ability to solve practical production problems. Transdisciplinarity is becoming the key and main vector for the development of technological education. Approaches to teaching are emerging that are able to translate the ideas of duality and transdisciplinarity into specific educational programs. The article discusses the relationship and dependence of these factors among themselves. Despite tangible changes, engineering education is still not without problems. The purpose of this article is to discuss the pain points and possibilities of the STEM approach. The methodological basis of the research is the reflection of theoretical views on engineering economics, technological education, transdisciplinarity in the training of engineers of the future; analysis of pedagogical and research experience in the field of technological education; local survey of experts, conducted in March 2023, in order to identify problem areas and prospects for STEM education. The results showed that the expansion of technological educational space can be facilitated by the development of transdisciplinary research and projects, convergent technologies, and the practice of solving life problems with the help of diversified professional groups.

Key words: engineering education; STEM approach in education; learning space; innovative engineering design; trans-disciplinarity; learning environment; modern educational landscape

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Introduction

The «Silver Bullet» has become a vivid symbol of a technological breakthrough, a super-universal solution to a complex task or problem. The growth of technologies, including digital ones, in the conditions of unstable economic development require an appropriate engineering education. And technological education, tired of constant reform, in turn, urgently needs a super-method, like a «silver bullet» [Blinov, 2020].

In the modern ideology of vocational education, the duality of training engineers of a new formation is chosen as one of the reference points, which implies, combined with high-quality theoretical training, the cultivation of the potential of future «techies» to effectively solve production problems. Transdisciplinarity is seen as another reference point, another and very important vector for the development of polytechnic education [Rozin, 2020]. «Lines of demarcation», which previously firmly separated various areas of knowledge, today become barely noticeable. The boundaries between different disciplines turn out to be less rigid than 10–20 years ago, much more hermetic and plastic. In the areas of intersection of previously «unfriendly» subject areas, previously unthinkable directions of academic research appear [Danilaev, 2021]. Another consequence of the work of the principle of transdisciplinarity is the activity and tangible results of the work of combined experimental communities, their bright research developments that give rise to new experiments. At the same time, transdisciplinary concepts become the basis for innovative technological design [Bajborodova, 2021].

The practical implementation of ideas originating within the framework of the transdisciplinary paradigm is the STEM educational model. It is based on the intersection of different disciplines. S-science (science), T-technology (technology), E-engineering (engineering), M-mathematics (mathematics) – this is the decoding of this fairly well-known American designation in pedagogy and engineering today. The vigorous promotion of STEM technology in schools and universities, on the one hand, is a progressive attempt to oppose the integrity of laboratory, academic and practical knowledge to the established isolation of academic disciplines; on the other hand, it is a pedagogically justified desire (with the aim of moving forward together with students in a healthy logic of interdisciplinary knowledge) to find opposition to such a teaching tradition that forgets about methodological knowledge and, resigned to the exponential growth of facts and disparate information in the depths of numerous subject areas, generously gives them for memorization. Test methods for presenting and controlling knowledge, unfortunately, have significantly moved today's education away from the cultivation of useful skills and abilities. Namely, they are more likely to guarantee the applicability of knowledge in real practice (arranged, in fact, in a multidisciplinary manner) and make engineering work and modern high-tech professions closer and more understandable for the new generation, give young people the opportunity to move in a career in the engineering and technical field [Bryanskaya, 2021]. In order for knowledge to serve a multifaceted practice, knowledge itself must strive for «voluminousness», and the teacher must move away from the intention to immerse and drown students in an ocean of information growing exponentially at the junctions of non-overlapping subject areas.

Research methods

The methodological basis for the reflection of the theoretical and practical aspects of engineering education and the proposed reasoning and conclusions was the web content of the official pages of Russian secondary and higher educational institutions. The reference was the presence in the description of the educational activities of these educational organizations of the terms «engineering economics», «technological education», «interdisciplinary», «innovation», «STEM education», «engineering design», «engineering enterprise», «mindfulness». We were interested in the meaningful positions of expert teachers teaching in schools, colleges, polytechnic universities, who in their daily work are faced with acute moments and opportunities for the STEM direction in education. The study used such methods as analysis, generalization and systematization of the views of theorists and practitioners on engineering economics, polytechnic education, transdisciplinarity, convergence in education and the continuity of education of an engineer of the future; generalization of individual scientific, pedagogical and experimental experience in education; a series of expert interviews conducted in March 2023; comparison, generalization of respondents' opinions.

Forty-two participants were asked a series of questions:

1. How do you imagine STEM technology?
2. What, in your opinion, is the relevance and prospects of the STEM approach in education?
3. In what way do you see the advantages of STEM technology in comparison with other practices?
4. What changes does the STEM approach bring to the modern educational space?
5. What is the degree of readiness of today's school for the introduction of STEM technologies.

Research results

The engineering approach to any development is, according to the majority of participants in our study, the basis of STEM technology. This is the opinion of 87 % of the interviewees. For example, obtaining a model (full or partial) of a product being prepared for production involves the use of 3D prototyping technology. This significantly reduces the time spent on developing an experimental model. Additive manufacturing, in fact, turns into a «bypass technology», that is, after the creation of a CAD model, 3D printing comes. Here, translation from one language to another is required: the object seen in the mental plan must be described in technical language [Luksha, 2021]. The solution of this problem is feasible for people with engineering thinking. First, the task is set so that the result is as similar as possible to the image of the desired result. Second, the chances and implementation options are studied in detail. And this requires a wide range of knowledge. There is a formation and constant enrichment of the student's natural-scientific picture of the world [Merenkov, 2021]. So, according to the STEM model, the student is immersed in theory and immediately has the opportunity to test it in practice. Mathematics, physics, chemistry, biology are not taught separately, but in conjunction and in order to solve a specific technological problem [Didkovskaya, 2021].

Interviewees (68 %) note the growth of educational programs based on the STEM model. Universities and technology parks open their doors to technology companies that create their own experimental educational sites on their territory. In such STEM centers, schoolchildren and students have the opportunity to try their hand at real research work and, at the same time, in engineering projects [Kondrat'ev, 2022]. More than 70 % of the respondents develop this topic and claim that olympiads, robot festivals, tournaments are, on the one hand, points for demonstrating and expanding practical engineering skills, on the other hand, they are competitive platforms where relevant competencies are presented and start «social lift» to prestigious technical universities, and after graduation – to an attractive company [Stegnij, 2023]. Such cooperation is beneficial both for the university ("running in" STEM programs, the necessary industrial expertise with additional funding), and students (guaranteed high-quality, personalized, hybrid education with «flexible» skills in demand on the market, with a focus on teamwork and project activities, with the disclosure of potential, with adjustment to the needs of future employers), and technology companies (solution of the personnel issue and a number of strategic tasks of the company).

When using STEM technology, we get the opportunity to see the established tradition of learning in a completely different way, take rational moments, supplement it with modern positive components [Gromov, 2023].

Engineering design based on the STEM approach is an important and growing vector of development [Ardabackaya, 2021]. His position is being strengthened, as the natural sciences, humanitarian, artistic aspects are represented equally. 74 % of interviewees speak about this in various rhetoric. We are talking about the development of not only rational, but also creative thinking. The introduction of engineering inventions into life with the help of technological entrepreneurship is a demonstration of the synthesis of science and art [Karpushova, 2019]. The relevance and benefits of the approach are noted by more than 77 % of respondents.

STEM technology differs significantly from traditional education: if in a familiar school educational material is presented before a practical exercise is completed, then in the STEM approach, the task is first solved by trial and error, and then knowledge and theory are offered. This moment is noted as significant by 83 % of respondents.

Conversations with the participants in our study showed how much the relevance of the tasks of secondary and higher education has increased to accelerate the scientific and technological development of Russia. In order to increase the contribution of the secondary school to the development of the country in the natural sciences, one should pay attention, according to 63 % of the study participants, to the insufficient level of training of schoolchildren in this area. This is evidenced by the low interest in chemistry, physics, biology and the poor results of the OGE and the USE in these disciplines. One of the ways out is seen in changing the attitude to the training of subject teachers, in developing their knowledge and skills of an interdisciplinary plan, creating experience in their own work and managing interdisciplinary research projects, forming a communicative space in which there would be a place for solving problems and difficulties of questions associated with the natural science development of schoolchildren.

Modern schoolchildren determine the development of our country, create an image of its future. Therefore, it is necessary to develop skills and abilities that ensure not only individual success and wellbeing in the life of each graduate, but also those competencies that determine the success of the country in which they grow up and will live on.

A number of problems hinder the solution of this problem today. One of the most important is the relatively low level of scientific literacy of a huge part of Russian schoolchildren. This level is partly characterized by knowledge in the field of chemistry and physics. The low marks of graduates in the general and unified examinations in these subjects (especially in the last three years) indicate precisely this: progress in the field of theory in these disciplines is not great. There are surprisingly few students who have received more than 80 points in chemistry and physics at the Unified State Examination. This implies the conclusion that modern schoolchildren are not ready to master disciplines related to technological production in higher and secondary specialized educational institutions (these disciplines are based on knowledge of chemistry and physics). The school, unfortunately, does not prepare the basis for highly professional engineers and designers to appear in the country in four or six years – «techies», in the old, familiar sense that we respectfully put into this word. And this means that the true technological sovereignty of the country, which, as we see it, is directly dependent on the quality of personnel, is under threat.

Challenging the need for scientific literacy of schoolchildren is becoming an increasingly meaningless exercise, especially in the current situation. On the contrary, the study of physics and chemistry should be given more attention. It may even be absurd to discuss the importance of their deep mastering at school in principle, since physics and chemistry cover almost all natural phenomena, they are associated not only with epistemology and philosophy, but also with everyday practice. Any phenomenon of life and nature can be viewed from different angles and explained from the point of view of different disciplines. So, Russian graduates of recent years are not able to explain many natural phenomena with the help of physics and chemistry, since these disciplines are either taught at an insufficiently high level, or are excluded from the program, that is, they are not taught at all in high school (such is the peculiarity of the current profile learning).

Here it is necessary with full responsibility to give an account of the fact that not only the natural-science literacy of each individual young person suffers, but their ability to solve practice-oriented tasks posed by social life is called into question. As a rule, these tasks are interdisciplinary in nature. In the diversity and usefulness of physical science for explaining a huge number of natural phenomena, in its inseparability from epistemology and philosophy, they were almost always sure, but for some reason today the relevance of ensuring natural science literacy has faded into the background, and the deficit of this literacy has become so critically noticeable.

The results of a number of studies on the quality of school education indicate that the graduates of Russian schools today do not have natural science competencies at a good level. Graduates, it can be said, are not ready to confidently participate in educational and life situations related to natural science and technology.

Another problem that did not find its solution was the fragmentation of knowledge in different disciplines. It must be admitted that outwardly everything looks quite worthy: the terms «meta-subject educational results», «interdisciplinary concepts», «universal learning activities» have firmly entered the lexicon of subject teachers, they are abundantly used in plans and reports [Gromov, 2023]. However, in practice, teachers rarely «go beyond» their subject and practically «don't let out» students. There are quite rational explanations for such tightness: actions in line with an interdisciplinary approach to learning lead to the lack of manifestation of subject-specific results in specific disciplines, and this is required by existing plans (17 % of interviewees); there is no holistic and step-by-step clarity on how to organize the educational process, as there is not enough knowledge in related and other areas (46 %); there is an obvious shortage of personnel in the implementation of bold educational ideas (37 %); there are great technological difficulties and colossal labor costs in the preparation of the educational program (62 %); there is a discrepancy between the educational program and the curriculum (34 %); subject teachers are faced with the unpreparedness of educational materials and, most importantly, educational environments for the application of this educational approach (24 %) [Poholkov, 2022].

Discussion

One cannot blame the Soviet and post-Soviet schools for not setting themselves the task of improving the quality of education. On the contrary, thanks to the inexhaustible resource of reform, the desire to improve education at its various levels was constantly felt, progress in the field of the quality of education was carried out in huge numbers. However, the reforms did not affect the science-intensive sphere. Physics, chemistry, mathematics have always been given at a very decent theoretical level. As for natural science literacy and the practical use of the achievements of these sciences, here we can state the weakness of training programs. But the state found mechanisms to compensate for the strategic miscalculations of education. For example, by importing high-tech goods, or by importing technology. True, earlier these miscalculations were not so noticeable and did not reflect so much on the development of the country.

So, the need to accelerate the technological development of the country has become more urgent. Consequently, there was a need for a more serious attitude to the formation of a personnel reserve focused on life in Russia and activities in the science-intensive and technological areas of its economy.

At least two factors influence the solution of this problem: 1) the desire of each graduate of a school or university to benefit his native country, and this attitude is formed by the family, a long educational process organized by the school, of course, the quality and nature of teaching the humanities disciplines (literature, geography, history, social science and other subjects that create a broad "picture of the world" of a person and a future professional); 2) the ability to be useful (and this is precisely the contribution of the disciplines of the natural sciences). Here we are talking about technological sovereignty. It is, in fact, fundamental, since it indicates whether the state is able to ensure the functioning of industry and scientific and technological development in order to ensure the high-quality work of its own technologies and infrastructure, and they, in turn, would guarantee the independence of the economy, defenses and policies against imports. Therefore, today there is an obvious need for high-class workers, competent engineers, technologists, designers – those same «techies», dreamers and creators [Baskakova, 2019]. And the basis for their technological literacy is formed by mathematics, physics, and chemistry. At the same time, it should be emphasized that the high level of teaching these disciplines at the theoretical level (and this cannot be taken away from the Russian school) does not lead directly to the same decent level of skills that ensure the technological development and leadership of the country [Aganbegyan, 2021]. And, of course, the formation of natural science literacy of schoolchildren should take place in conjunction with the development of a worldview focused on love for the motherland and the desire to benefit people [Azoev, 2021].

Conclusion

If the school is unable to cope with these tasks, then there are serious threats. On the one hand, this is a threat to the country – due to the impossibility of creating a comprehensive high-level technological sovereignty. On the other hand, for schoolchildren who are self-determining in life, who need to find ways that are useful and important for society to realize their strengths so as not to become a generation of «superfluous people» [Bodrunov, 2022]. There is also a threat to schools, secondary and higher, due to the loss of state confidence in the ability of the education system to solve educational and educational tasks that are significant for society. Today, such a task is to ensure technological sovereignty [Moiseeva, 2022]. This is not the first time such a task has been posed. Not only the courage of the soldiers, but also the intellectual potential of the people, technological knowledge, formed at a high level by the Soviet school before World War II, made it possible to create inventions and discoveries that brought victory closer. Can the current educational system make its contribution to the scientific and technological development of the country?

STEM technology is consonant with the goal and has serious advantages in comparison with other approaches used to train engineers (IT specialists, Big Data engineers, application and information security programmers, design engineers of robotic systems and automatic devices, neural network programmers). STEM education carries elements of transdisciplinary and project-based learning. In fact, the desired integrated form appears, which provides the opportunity to use the knowledge gained at school and university to create a useful product [Romanova, 2020]. As for the pedagogical plan, in this case, the development of critical and, which is very significant, independent thinking takes place (its formation within the framework of a theoretical approach is significantly difficult). The students are growing confident in the correctness of the chosen specialty, in their professional significance. Bringing a technological idea to life with the use of modern tools strengthens self-esteem, a conscious understanding of involvement in engineering grows. Teamwork gives schoolchildren and students the opportunity to try themselves as a leader or a participant in a discussion, to make decisions together. The idea of the duality of polytechnic education is embodied in specific developments that are significant for the country's economy [Rudskoj, 2018]. The need for disciplinary convergence in engineering education is becoming quite justified.

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