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STEM-APPROACH TO THE TRANSFORMATION OF PEDAGOGICAL EDUCATION

Nadiia Balyk, Galyna Shmyger, Yaroslav Vasylenko, Vasyl Oleksiuk, Anna Skaskiv
Department of Computer Science
Volodymyr Hnatiuk Ternopil National Pedagogical University
2 M. Kryvonosa St., Ternopil, Ukraine 46027
{nadbal, yava, shmyger, oleksyuk, skaskiv}@fizmat.tnpu.edu.ua

Abstract: *STEM-education is one of the important areas of the educational reform of XXI century. Modern initiatives in the field of STEM require the development of a model for transforming education that would correspond to contemporary demands of society. Such a general scenario and preliminary statement confirm the thesis underlying this research: there is a need to transform the existing model of training, first of all, pedagogical staff from classical education to innovative STEM-education. It was found that institutions and scholars are searching for new approaches to prepare people for solving real problems of the surrounding world through different STEM-approaches in education. In the article, the authors describe the transformation model of education for the introduction of the STEM-approach in a pedagogical university in order to prepare educators of a new formation and the main indicators of its effectiveness.*

Keywords: a model for transforming education, STEM-education, STEM-approach, STEM-practices, pedagogical university

INTRODUCTION

STEM-education is one of the most important areas of educational reform in the XXI century. The world of the XXI century involves competition at the global level, so countries have to invest a lot in STEM-education (Breiner et al. 2012, Kennedy, Odell 2014).

Modern digital technologies, STEM-technologies, which are becoming the foundation of an innovative economy, place new demands on staff at all levels:

- a request for qualified STEM-workers with practical skills in working with complex technological objects, with a new type of engineering thinking;
- a request for specialists with general STEM-literacy and general skills of problem-oriented thinking, that is, those who possess digital and social competences for the formulation and execution of the tasks in any and professional field.

All these requests over the last few years have been widely developing in connection with state and public attention to the IT-sector in Ukraine. Due to this attention the problems in education and staff training have been highlighted and discussed: the shortage of personnel for high-tech industries; low grades and poor knowledge of school graduates; the weakening of the natural-scientific and technical component of secondary education; weak professional orientation and the desire to master advanced technologies.

It is necessary that young people will be ready and would like to continue the STEM-career. Young people should understand that STEM is not fun and games; they must be ready to take on themselves the solution of the problems that arise in a constantly developing world. (Pittinsky, Diamante 2015).

These problems require not just the improvement of education, but also the search for new approaches for preparing people to solve real problems of the surrounding world. Therefore, nowadays more and more attention is focused on the so-called hybrid skills, when humanitarian and technical skills are equally well developed. To do this, it is necessary to train new generation teachers who are able to develop integrated STEM-skills for pupils and students. The teachers are constantly faced with new training strategies and techniques needed for successful STEM-learning and STEM-skills development. (Williams et al. 2015, Lund, Stains 2015). *As noted in* Williams et al., the concept of the STEM-approach varies greatly among educators, education researchers, curriculum developers and educational policy makers (Williams et al. 2015).

1. BACKGROUND

The STEM-approach is a wide range of actions, practices and techniques that are geared towards ensuring that society and humans will be ready for the future. These practices are only being developed today, and there is no definitive concept that would precisely and unambiguously determine the boundaries and frames of STEM-education. However, in recent years in different countries, a great deal of experience was received in the development of education in this direction. Reflection, analysis and special studies allow us to generalize and present the most significant characteristics of this approach.

The GoStem programme (https://www.go-stem.org [accessed 12 June 2019]) defines STEM as an educational approach based on the natural connection of four disciplines, and highlights its key principles: applied character to the real world problems; learning through problem solving and critical thinking; integration of different content. Based on empirical data it is confirmed that the engineering design process can be an effective way to promote and support the integration of concepts from several disciplines of STEM (Estapa and Tank 2017; Guzey et al. 2016). The edition (Moore et al. 2014) *defines the process* of engineering design as an important practice and the main disciplinary idea that students must master.

A number of conceptual approaches to integrated STEM-learning *were proposed* (Asunda and Mativo 2016; Kelley and Knowles 2016; English 2016). *According to* Bouwma-Gearhart and Milner, an interdisciplinary approach to pupils' learning and their immersion in the modern learning environment is a prerequisite for STEM-education (Bouwma-Gearhart 2014; Milner 2015).

The authors of (Stanford et al. 2016) *state* that the implementation of cross-links in STEM is a complicated procedure that obliges teachers to disclose the content of STEM-disciplines in the context of learning to solve real problems. Today, cross-links are recognized by many educational researchers, as there are clear results that inclusion of STEM-education can help learning of students to solve the tasks from life (Stanford et al. 2016).

Dalimonte *notes* that teaching how to solve problems in a global perspective is not as difficult as it might seem. Pollution, food production and energy are topics that can be explored through STEM-projects (Dalimonte 2013). STEM-education can help the next generation of students to solve real problems by applying concepts related to both disciplines and the development of critical thinking, cooperation and creativity (Burrows and Slater 2015, Roberts, 2013).

The STEM-approach in education focuses on new needs in staff resource and community development. For the education system, this is a question of the content and goals of modern education. The whole world is searching for this answer, offering different options.

Today, two main lines *can be identified* in the search for answers to this question: the development of STEM-literacy for all and the in-depth training of staff for high-tech industries.

The development of STEM-literacy for all

Providing each student with innovative thinking tools and experience in how to use mathematics, engineering and science to solve various professional tasks: the development of logic and thinking; the ability to set and solve tasks; the ability to investigate, analyze, prove; the teamwork, communication; the creativity; digital literacy.

The training of staff for high-tech industries

In-depth STEM-training of motivated senior pupils and students to enable them to succeed in science and technology: the motivation for engineering and technical specialties and careers in science and technology; access to laboratories where experiments are conducted and industrial tasks are solved for experience and practice; the absence of barriers to career and professional growth.

Two of these views on the development of the education system are not mutually exclusive but provide for different STEM-approaches and strategies for actions. In the case of emphasis on STEM-literacy, the review of the content and principles of the organization of education becomes the topical tasks for all. The emphasis on the training of highly trained staff draws attention to the organization of channels for access to the necessary knowledge, the elimination of barriers, the creation of additional conditions and the general interest in the scientifically and technically oriented sector of the economy. For the further development of STEM-education models at the level of the entire system, it is important to distinguish between processes such as training, functional literacy, learning and education in a narrow sense.

It can be said that at the level of conceptualization and development of the approach for appealing to STEM – this is first and foremost an indicator of the actualization of all alternative approaches and ideas in the field of pedagogy and education. The initiatives undertaken by different actors require an expansion and deepening view of the STEM-approach in education, acquaintance with *conceptual and practical* developments, and the development of *own model of the movement* of Ukrainian society and schools for new education based on the best world educational practices.

There are various practices aimed at the development of conceptual, methodological supporting of the STEM-approach in education:

- the organization of research, analysis of existing practices, their systematization and conceptualization (Morze, Smyrnova-Trybulska, Gladun 2018; Encouraging STEM studies. Labour Market Situation and Comparison of Practices Targeted at Young People in Different Member States 2015);
- the creation of pilot projects or experimental STEM-schools, where new methods are being approved and recommendations and methods for further dissemination, reproduction are being developed (Smyrnova-Trybulska, Morze, Zuziak, Gladun 2017; LaForce, Noble, King, Century, Blackwell, Holt, Ibrahim, Loo 2016);
- the development and approval of new educational subjects working in the interdisciplinary approach ("Technology", "Science", "Modeling"), the emphasis on problem-oriented craft and technologies, the development

and creation of products (Thorsteinsson, Olafsson, Autio 2012; Shmyger, Balyk 2017);

– the creation of the programmes for assessing the level of youth involvement in the STEM-sphere, the developing methods for assessing the effectiveness of national and local programmes (Stohlmann et al. 2012; Kelley, Knowles 2016).

2. RESULTS AND DISCUSSION

A model for transforming education to implement the STEM-approach was created at Ternopil Volodymyr Hnatiuk National Pedagogical University (TNPU) by scientists of the Department of Computer Science. This model has been approved during 2016-2018 at the Faculty of Physics and Mathematics and at scientist-research STEM-centre.

Summarizing the experience of the approval of the transformation model of education at TNPU through the implementation of the STEM-approach, we highlight the following most effective directions of action (Figure 1).

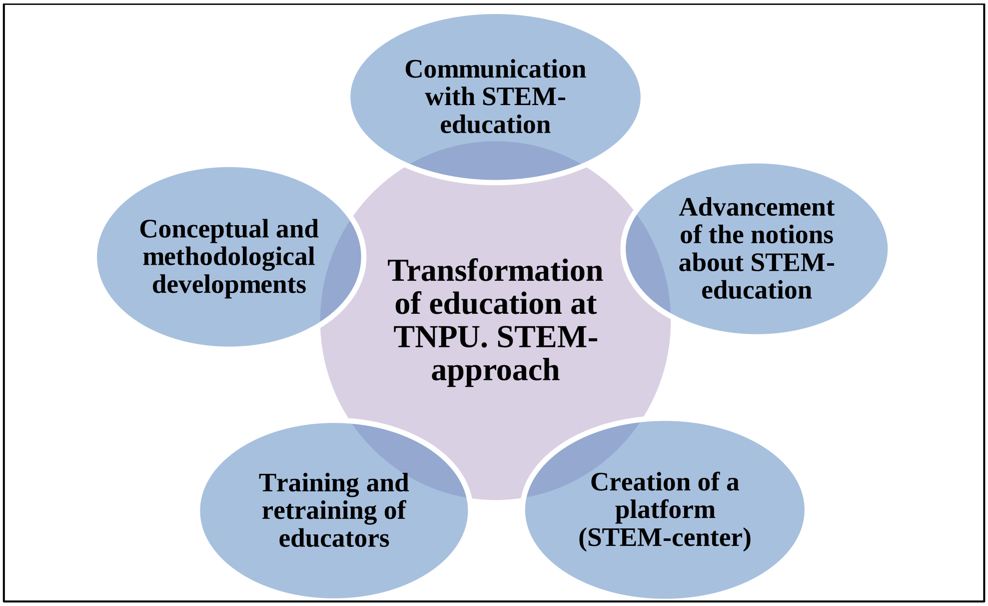

Figure 1. STEM-approach. Transformation model of education at TNPU
Source: *Own work*

1. Increase the intensity of communication on the topic of STEM-education. The content of this communication was determined by a wide range of issues that needed discussion, from simple acquaintance with those who work on this topic, practicing at different levels and in different fields, sharing experiences, problems and difficulties, and ending with communication regarding the new content of education, development of new programmer and concepts. Today the various formats of such communication are in demand: speeches, discussions about actual problems, the exchange of experience and the presentation of techniques, practices, working groups and joint projects.

Commonly, different subjects are involved in the promotion and implementation of the STEM-approach in education. These are government agencies and structures, local communities and self-government bodies, businesses and corporations, separate educational institutions and networks, public associations, professional communities and individual educators. Each of them chooses its strategy of action, based on the general situation, their interests and opportunities.

In the TNPU, for the creation and development of links between different actors, we took into account factors such as:

- building links between different educational institutions, academic and business entities to give pupils and students the opportunity to participate in internships and work on real projects, building effective communication: university – school – community – private companies – regional authorities;
- creating continuity in STEM-processes from school to university and to work place, increasing the applied value of choosing STEM-professions;
- organizing various events for active communication, sharing experiences and finding partners for joint activities;
- the creation of platforms and resource platforms, where new developments, models and samples are concentrated, and they become available for study and application;
- educational management, crowdfunding, sponsorship, fundraising, leadership in education.

The union with higher education, with the practice and industry of the city ensures the development of social responsibility, involvement of the university in solving the problems of the local community, provides a flexible and practical vocational guidance.

2. The promotion of STEM-education concepts among the general public and above all among parents, teens and other potentially interested individuals. This direction – providing public request and the demand for STEM-education. It is about clarifying the relevance of the engineering business, the scientific approach, the development of technologies and, together with them, the significance of the STEM complex for future quarries. This direction meant the exit in the media, on the platforms and parents' communities, the creation of special projects and initiatives in the field of PR.

One of such projects was the grant project "Popularization of STEM-professions", which was supported by the programme of the British Council "Active Citizens". Within the framework of the project there were organized interactive educational excursions, out-of-school schools, forums, festivals, STEM-workshops and other events, where a demonstration of new initiatives, achievements and perspectives in the development of STEM in the pedagogical university took place. STEM-excursions as a special type of integrated training sessions at the university have provided an opportunity to enhance pupils' motivation to STEM-disciplines through familiarization with real STEM-projects, for example, "3D printing of historic castles in Ternopil-land". The master classes provided the opportunity to create STEM-projects for pupils, useful for local communities, to develop their technological, career and life skills.

At the local level, the project "Popularization of STEM-professions" increased awareness of 7-11 grade pupils with such STEM-professions as an 3D-printing engineer, internet of things architect. As a result of the project, more than 300 pupils of general secondary education institutions of the city Ternopil and Ternopil region were involved in the selection of the future profession in the field of natural sciences and mathematics. This will allow in the future to increase the number of students by STEM-direction in higher education institutions of the Ternopil region and to train highly qualified specialists with STEM-skills that will be ready to solve modern innovation projects within the boundaries of the region and Ukraine as a whole. Conducting educational events aimed at the promoting the STEM-professions will enable to realize creative potential of young people to solve non-standard tasks, orienting on the needs of the community and its sustainable development.

3. The creation of a platform (STEM-center TNPU, http://stem.tnpu.edu.ua/), methodological hub as a place of gathering and constant exchange of experience, techniques and ideas. Because of the disparity of people and initiatives and of the lack of ready solutions in STEM-approach, it was necessary to create a platform for the functioning of separate STEM-components. Scientific-Research STEM-centre of the Faculty of Physics and Mathematics became a place for the emergence of initiatives, the development of individual projects and a permanent platform for communication of various stakeholders.

The resources for teaching STEM-disciplines in schools and at a pedagogical university have been aggregated in this centre, it is conducting the search for methods and approaches for implementing STEM, it is systemizing and accumulating different experiences of successful educational STEM-practices.

During the transformation of pedagogical education at the TNPU, such STEM-practices have been approved and implemented:

- *the cooperation with pilot STEM-schools*. Each such school has its own unique context, conditions of activity, principles, implementation of which characterizes STEM-education at the level of a separate school. The researchers of the Department of Computer Science at TNPU advise the leadership of individual schools on the implementation of the innovative model of STEM-education in their educational institution;
- *the effective career guidance among pupil and student youth*. The opportunity for young people to get acquainted with modern and perspective professions, to try themselves and to choose the own future profession;
- *the development of motivating platforms and formats* (scientific picnics, hackathon, Olympiads, contests, STEM-festivals, STEM-tours, STEM-workshops).

4. Training and retraining of teachers and practitioners involved in education. Most of the teachers received instruction only from one discipline (Honey et al. 2014). This poses a serious challenge for educators and administrators who are interested in the promoting of integrated STEM-learning. Therefore, the deployment of STEM-programmes requires retraining of educators and managers. For this aim, the STEM-teachers support programme was adopted at the university (the development of professional competence of educators, motivation, opportunities, successful experience) (Balyk, Shmyger 2018). At the Faculty of Physics and Mathematics there is organized the training of pedagogical STEM-personnel to increase teacher qualifications focusing on enhancing their professionalism in the field of STEM.

At the STEM-centre of TNPU there is pursued following:

- the creation of programmes (short-term and long-term) for training and retraining of pedagogical staff;
- the development of programmes, methodology and methodological materials for the staff of educational institutions on implementation of innovative learning technologies, case-study technologies, interactive methods of group learning, methodology for critical and system thinking development; the creation of pedagogical conditions for obtaining resultative individual experience of project activity and the development of start-ups;
- the internships and sharing of experiences, the inclusion of educators in networks and communities practicing STEM-education.

The result of retraining and advanced training is the development of STEM-education models for various educational levels, the creation of cases with scientific and methodological materials, cases for implementation of cross-cutting lines of STEM-subjects and for the development of STEM-lessons and excursions, the mastering of interactive teaching methodology, the developing of professional competences on STEM-based learning.

In the city of Ternopil there is a «School of New Formation Educators», which is conducted by teachers of the Department of Computer Science of TNPU. While working in the pedagogical workshops of the school, educators are studying STEM-education models for different educational levels, elements of STEM in different components of the education system. Studies and projects have their own forms and levels:

- in kindergarten and elementary school, the emphasis is on research the mastering of concepts and procedures that are related to scientific and research activities, and the research activity itself takes place in small groups;
- in secondary school serious attention is paid to preparing children for implementation of practical projects through real and training project activities in learning groups;
- in the high school, the core of the training is a practical project research activity that involves the inclusion of children in educational, research or professional projects run under the curatorship of university.

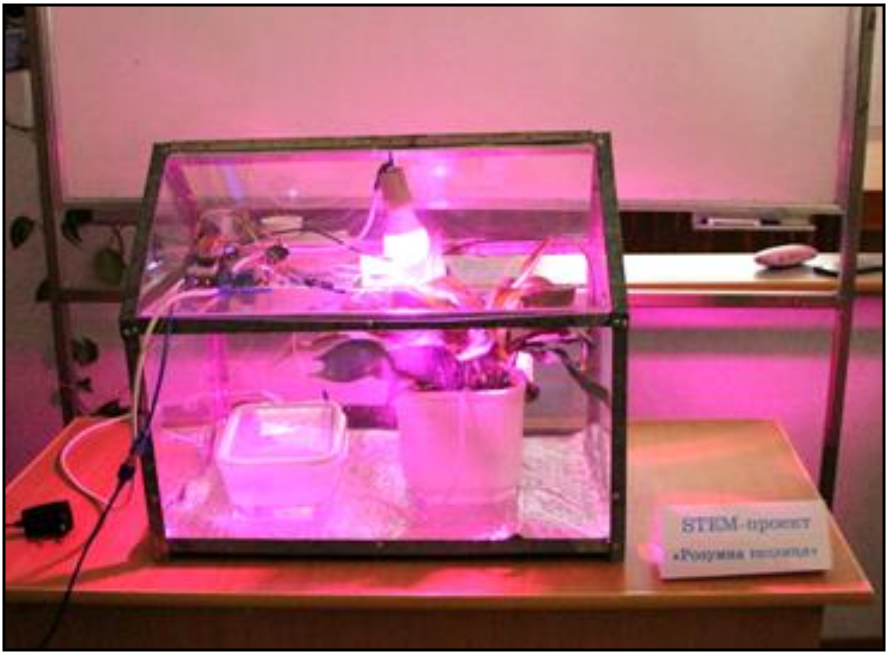

Figure 2. STEM-project «Smart greenhouse», created at the STEM-center of TNPU

Source: Own work

The importance was given to training in research practice, the inclusion of teachers in real research and engineering university projects such as «Smart greenhouse» (Figure 2), «Smart house» (Figure 3). These projects were created jointly by the teachers of the Department of Computer Science and students of the specialty «Informatics» for training in the creation of models of intelligent objects, their prototyping and research.

This means that retraining did not take place in a closed educational system, but was part of the collaboration with university scientists. The peculiarity of the practice was the involvement in the educational process of those who can include in their actions a practice and show how to do it.

Figure 3. STEM-project «Smart Home», created at the STEM-centre of TNPU
Source: Own work

5. Conceptual and methodological developments *of the transformation model of education in the direction of STEM*, the search for interdisciplinary content and methods of its transmission. This work was carried out by the teachers of the Department of Computer Science in interaction and coordination with the Institute of Education Content Modernization of the Ministry of Education and Science of Ukraine (Kyiv), the Ternopil Communal Methodological Centre for Scientific and Educational Innovations and Monitoring (Ternopil), the City Administration of Education and Science (Ternopil), the Regional Department of Education and Science, the Directorate of General Secondary Education Institutions of the United Territorial Communities.

The basic level of implementation of the STEM-approach in a pedagogical university is the planning of educational programmes, curricula and individual special courses. Let's highlight some important principles that we use to develop programmes of such special courses:

- the use of «open» tasks, allowing to search for solutions in various fields of knowledge; tasks and problems in which there are many solutions;
- the movement from the solution of practical and specific tasks to the concepts of a higher level of abstraction, ideas and theories (**Systems thinking**);
- the use to find a solution to the problem of the corresponding mathematical apparatus, focusing on arguments, proofs and logic;
- inclusion in the discussion and resolution of problems with the use of digital technologies (**Digital Technologies**), computational thinking (**Computational thinking**);
- the possibility of handmade organizing, conducting experiments; designing from improvised materials with the use of design-thinking (**Design thinking**), engineering design (**Engineering Design**);
- the teamwork organization, presentation of the received results before the group, discussion and mutual evaluation in the group (**Project management**).

A purposeful reformation and correction of educational programmes is carried out at the university. STEM-disciplines in one or another form are included in the programmes of specialties «Informatics», «Mathematics», «Physics», «Chemistry», «Biology», and in addition a programme for the development of digital entrepreneurial competences appears at the master's level.

In particular, university special courses such as «Design», «Design of thinking», «3D-modelling», «3D-printing», «Smart digital laboratories» etc. are taught. They refer to both the integration of knowledge from different fields and the development of student and masters' work practices over STEM-projects. These special courses are aimed at teaching students and teachers to solve real problems and are based on technologies. (Figure 4):

Consequently, the main characteristics of the transformation model of education at TNPU in the field of STEM are:

- the learning is built on problem solving (problem-based learning);
- the emphasis on "local" issues (rigorous learning), communication with external communities (external community);
- development of technological, career and life skills (career, technological and life skills).

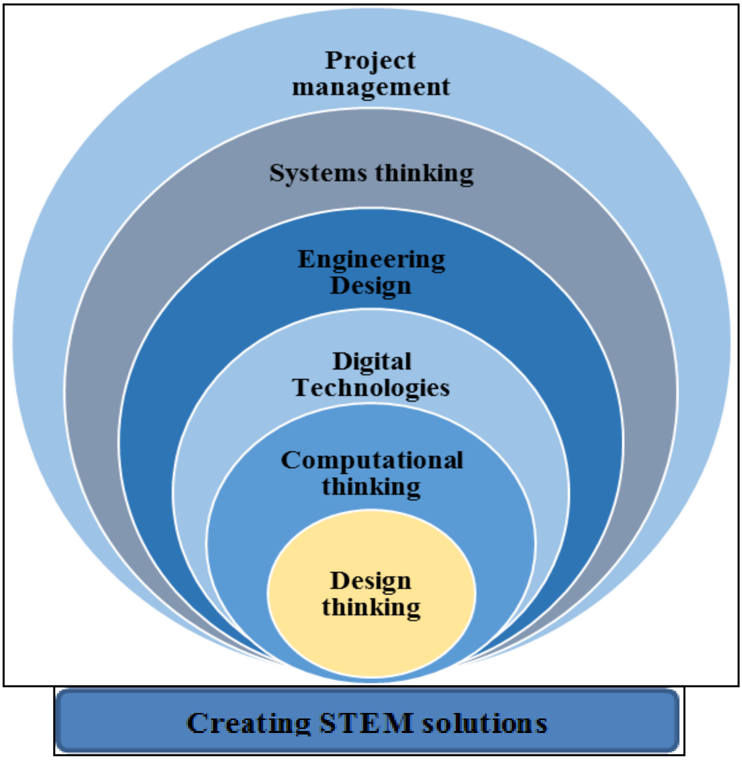

Figure 4. Technologies for solving problems in STEM-projects
Source: Own work

CONCLUSION

An overview of the state of STEM-education allows you to make some general conclusions. First, the intensity and diverse-plan of STEM-search can be seen as a vivid symptom of exigent transformations in education. It signals the inconsistency of the existing education system with either the innovation process or the challenges facing the individual in her individual development. Today, the STEM-approach is an area of active search, experimentation and innovation in education.

Secondly, in spite of the concentration on natural sciences, engineering and technology, the issue of STEM-education is a matter and problem of humanities–and social sciences, but first of all of methodology, management, organization of activities.

Third, STEM is the place for everyone. For the development of STEM-education, it is important to include a wide range of participants, each of which finds its own niche and its interest.

In the course of the study, the transformation model of education for the implementation of the STEM-approach in TNPU was approved, which included: increasing the intensity of communication on the topic of STEM-education, promoting the conceptions of STEM-education among the wide public, creating a scientific and research STEM-centre, conceptual and methodological developments of the transformation model of education in the direction of STEM, the training and retraining of educators and practitioners involved in education.

The main indicators of the transformation results of STEM-education at the university are: active participation of pupils, students, teachers in STEM-learning opportunities, interest in themes, concepts and practices of STEM, ability to participate productively in STEM-research processes, ability to apply relevant life and career skills, awareness of the STEM-professions, understanding the value of STEM in society.

In the future, the experience of educators in conducting research and development, the inclusion in the educational STEM-programmes of practitioners who possess these skills and have their own experience, going beyond the traditional teaching practices are relevant for the Ukrainian situation.

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