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Building Readiness of Future Natural Science Teachers for Professional Activities Using Stem Tools

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ABSTRACT

Aim. The aim of the study is to determine the level of readiness of future science teachers to use the STEM approach in the educational process and to develop recommendations for the integration of relevant STEM tools into the educational process of Ukraine. *Methods*. The study involved the following methods: the focus group method, the two-phase survey, the accompanying survey, the variable impact method, and the statistical analysis. *Results*. Students majoring in natural sciences are poorly prepared for the integration of STEM tools. Students of the experimental subgroup became more ready to use STEM tools and developed a more structured vision of systemic issues. Comprehensive educational courses are an effective means of preparing future teachers for the integration of STEM tools in their future activities. *Conclusions*. STEM approach can be effectively integrated into teaching natural sciences through comprehensive educational courses and practical activities that develop the future teachers' skills. Virtual laboratory technologies demonstrated the greatest effectiveness. *Prospects.* Prospects for further research focus on the need to verify the obtained results for a wider sample of future teachers of natural sciences and other majors of higher education institutions (HEIs).

KEYWORDS: Computer languages, microelectronics, electronic learning, digital libraries, laboratory equipment, exhibitions, printing equipment

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La formación de los futuros profesores de Ciencias Naturales para actividades profesionales utilizando herramientas STEM

RESUMEN

El objetivo del estudio es determinar el nivel de preparación de los futuros profesores de ciencias para utilizar el enfoque STEM en el proceso educativo y desarrollar recomendaciones para la integración de herramientas STEM relevantes en el proceso educativo de Ucrania. *Métodos.* El estudio involucró los siguientes métodos: el método de grupo focal, la encuesta de dos fases, la encuesta de acompañamiento, el método de impacto variable y el análisis estadístico. *Resultados.* Los estudiantes que se especializan en ciencias naturales están mal preparados para la integración de herramientas STEM. Los estudiantes del subgrupo experimental se prepararon más para usar las herramientas STEM y desarrollaron una visión más estructurada de los problemas sistémicos. Los cursos educativos integrales son un medio efectivo para preparar a los futuros maestros para la integración de las herramientas STEM en sus futuras actividades. *Conclusiones*. El enfoque STEM se puede integrar de manera efectiva en la enseñanza de las ciencias naturales a través de cursos educativos integrales y actividades prácticas que desarrollan las habilidades de los futuros maestros. Las tecnologías de laboratorio virtual demostraron la mayor eficacia. *Perspectivas*. Las perspectivas de futuras investigaciones se centran en la necesidad de verificar los resultados obtenidos para una muestra más amplia de futuros profesores de ciencias naturales y otras carreras de instituciones de educación superior (IES).

PALABRAS CLAVE: Lenguajes informáticos, microelectrónica, aprendizaje electrónico, bibliotecas digitales, equipos de laboratorio, exposiciones, equipos de impresión.

Introduction

-Relevance

The integration of STEM tools into the educational process is becoming increasingly relevant in view of the pandemic restrictions and the development of distance education. The implementation of STEM technologies in higher education in the context of distance learning is especially important, as this approach enables students to continue their studies and receive quality education under the imposed restrictions. Besides, the development of STEM education contributes to the training of future specialists, in particular, future natural science teachers who will be able to work effectively with modern technologies and contribute to the development of science and technology.

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-Unexplored issues

In view of the current circumstances and world trends in the field of education and their special actualization in the context of military operations and post-war recovery in Ukraine, there are numerous studies on the introduction of STEM tools into the educational process. In particular, Buturlina (2023) provides general recommendations of mass introduction of STEM education in Ukraine. Pyurko et al. (2023) study the relevance of the integration of transdisciplinary competencies and practices into the Ukrainian educational process. Kuzmenko et al. (2023) explores the theoretical and methodological foundations of creating an ecological model of the environment in the context of STEM education. However, the determined research vector forms only the basic concepts of systematization, integration and implementation of STEM tools in the educational process in Ukraine and does not contain research and recommendations on the sectoral introduction of STEM tools in separate professional and qualification areas of the educational spectrum. These include lack or less detailed relevant results for future natural science teachers. So, there is an urgent need to study solutions for the implementation of STEM tools in the training of natural science teachers.

-Aim

The aim of the study is to assess the readiness of future science teachers to introduce STEM tools into the educational process with further development of adaptive recommendations for the integration of relevant STEM tools into the educational system of Ukraine

-Objectives/questions

Research objectives:

- study the range of STEM tools that can be integrated into the educational process for training future natural science teachers;
- carry out an empirical study on the effectiveness of each of the identified options for the use of educational STEM tools in the learning environment in the relevant professional field;
- analyse the results of research and provide practical recommendations regarding the implementation of STEM tools into the multidisciplinary educational programmes.

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1. Literature review

We will establish an actual and relevant factual background regarding the possibilities of using STEM tools in the educational process, including for the training of future natural science teachers.

Oladele et al. (2023) noted that students had positive experiences with online learning of STEM subjects using Google technology. Chakabwata (2023) notes the positive effect of amplifier technologies when integrating physics into mathematical sciences. The results of the study by Vasconcelos (2023) demonstrates the potential of STEM tools in developing the ability of university students to advance hypotheses and test them using simulation programming. Lapp et al. (2023) indicate that STEM tools can activate the interest and dynamic development of students' skills during the active study of mathematical and geometric postulates using digital means of dynamic geometry and robotics. Pope (2023) indicates the effectiveness of using specialized online resources such as Desmos and GeoGebra in the concept of STEM education.

Herrera et al. (2023) note the effectiveness of STEAM education with the use of microcontrollers. Günay and Yüksel Haliloğlu (2023) provide results on the effectiveness of online STEM education. Pérez Gutiérrez (2023) presents findings of a study on the educational impact of using cloud services in the STEAM-based learning paradigm. Vázquez-Villegas et al. (2023) found that the use of STEM tools such as software for statistical analysis of data and creation of graphic images, programming environments, virtual laboratories, etc. in the educational process enables students to develop research skills and enhances their interest in scientific work. Haag et al. (2023) considers the implementation of co-teaching as a tool for effective teaching of STEM subjects in universities. Chaka (2023) explores the possibilities of using artificial intelligence (AI), robotics and blockchain technologies in the educational process of HEIs in the context of the Fourth Industrial Revolution and STEM education.

The reviewed studies showed that the use of STEM tools in the educational process can enhance student motivation, improve their learning outcomes, develop students' scientific and research skills, and provide high-quality training of natural science specialists.

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2. Methods

2.1. Research design

The general research procedure involves the following steps of the algorithmic sequence:

1. Identification of STEM tools.

2. Development of a transdisciplinary course for training future natural science teachers in two variations (typical and experimental).

3. Formation of a focus group among students majoring in natural sciences.

4. Division of the focus group into subgroups: subgroup A (control) will take a classic academic transdisciplinary course, subgroup B (experimental) will take an educational course using STEM tools.

5. Conducting a repeated survey of focus group students (second phase).

6. Correlative and comparative statistical analysis of the survey results.

The sequence of research stages — Figure 1.

A survey was used to assess the actual state of awareness and favourability of implementing STEM tools in the educational process. It was based on a list of questions, which are combined into three logical blocks: informative, research and practical.

2.2. Sampling

The target group was formed from students of the 4th year of the Faculty of Chemistry, Ecology and Pharmacy of Volyn National University, which had 154 future teachers at the time of conducting this study. The focus group was divided into subgroups A (control) and B (experimental) arbitrarily. Subgroups A and B consist of the same number of participants, 77 students each.

2.3. Methods

The aim of this research was achieved by using the following methods:

- the method of focus groups was used to form a group of future natural science teachers;

- the survey method was applied to obtain empirical data;

- method of variable impact was used to verify the variable impact on subgroups A and B;

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- statistical analysis based on correlative analysis criteria was applied to carry out an analytical study of empirical data, generalization, averaging, correlative comparison, and identification of key aspects.

Figure 1. Research stages

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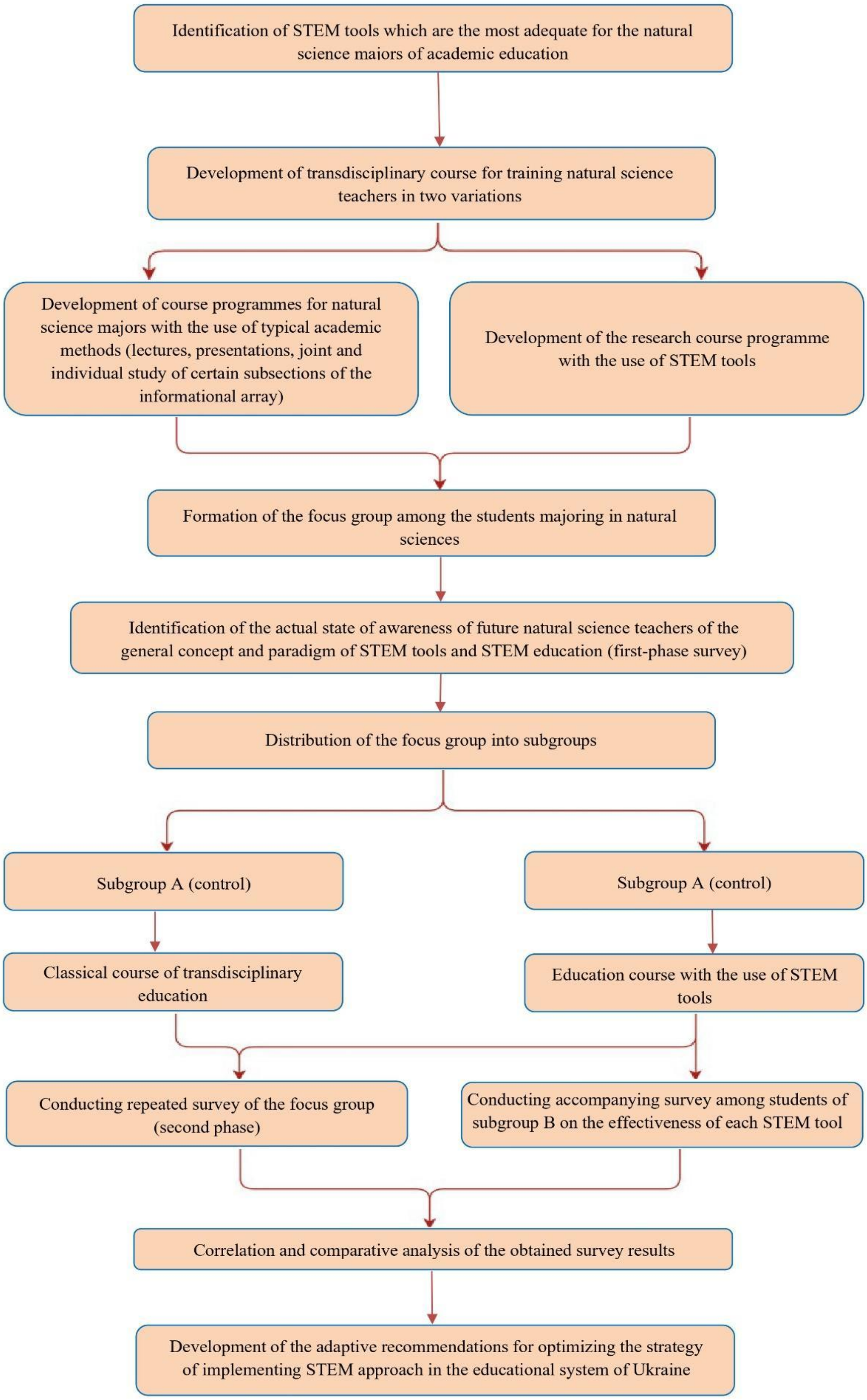

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2.4. Instruments

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The study used the following range of STEM tools that were used to develop an experimental educational course:

- 3D printing tools: 3D design Autodesk Tinkercad and PrintLab;

- Low Code/No Code programming: Codeblocks Autodesk Tinkercad;

- development of electronic circuits and microcontrollers: Circuits Autodesk Tinkercad;

- transdisciplinary virtual laboratories and simulations: PhET University of Colorado;

- transdisciplinary virtual exhibitions and tours with elements of augmented reality: Virtual & Augmented Reality (CoSpaces 360° tours, CoSpaces simulations, CoSpaces exhibitions, CoSpaces games) CoSpaces Edu.

2.5. Ethical criteria

1. Ensuring the safety and health of research participants.
2. Data collection is voluntary.
3. Ensuring objectivity of research and avoiding conflict of interests.
4. Compliance with scientific and ethical standards.

3. Results

In accordance with the proposed research design (Figure 1), we determine the range of STEM tools, namely 3D printing tools, Low Code/No Code programming tools, microcontroller simulation tools, virtual laboratory simulations, virtual and augmented reality (Figure 2), which are adequate to the conditions of training future natural science teachers at HEIs.

This was followed by the creation of the relevant transdisciplinary course for the training of future natural science teachers – Figure 3.

According to the results of the first phase of the survey (Appendix A), students majoring in natural sciences have low awareness of the mechanisms and benefits of using STEM tools in the educational process.

For subgroups A and B, influence was applied in the form of a developed transdisciplinary course, which differs in teaching methods (Figure 3).

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The results of the repeated survey (phase 2 — Appendix B) of the representatives of the control group (A) indicate a trend toward an increased level of receptivity to the concept of using STEM tools in the process of training future natural science teachers.

Figure 2. The list of STEM tools adapted to the educational training of future natural science teachers

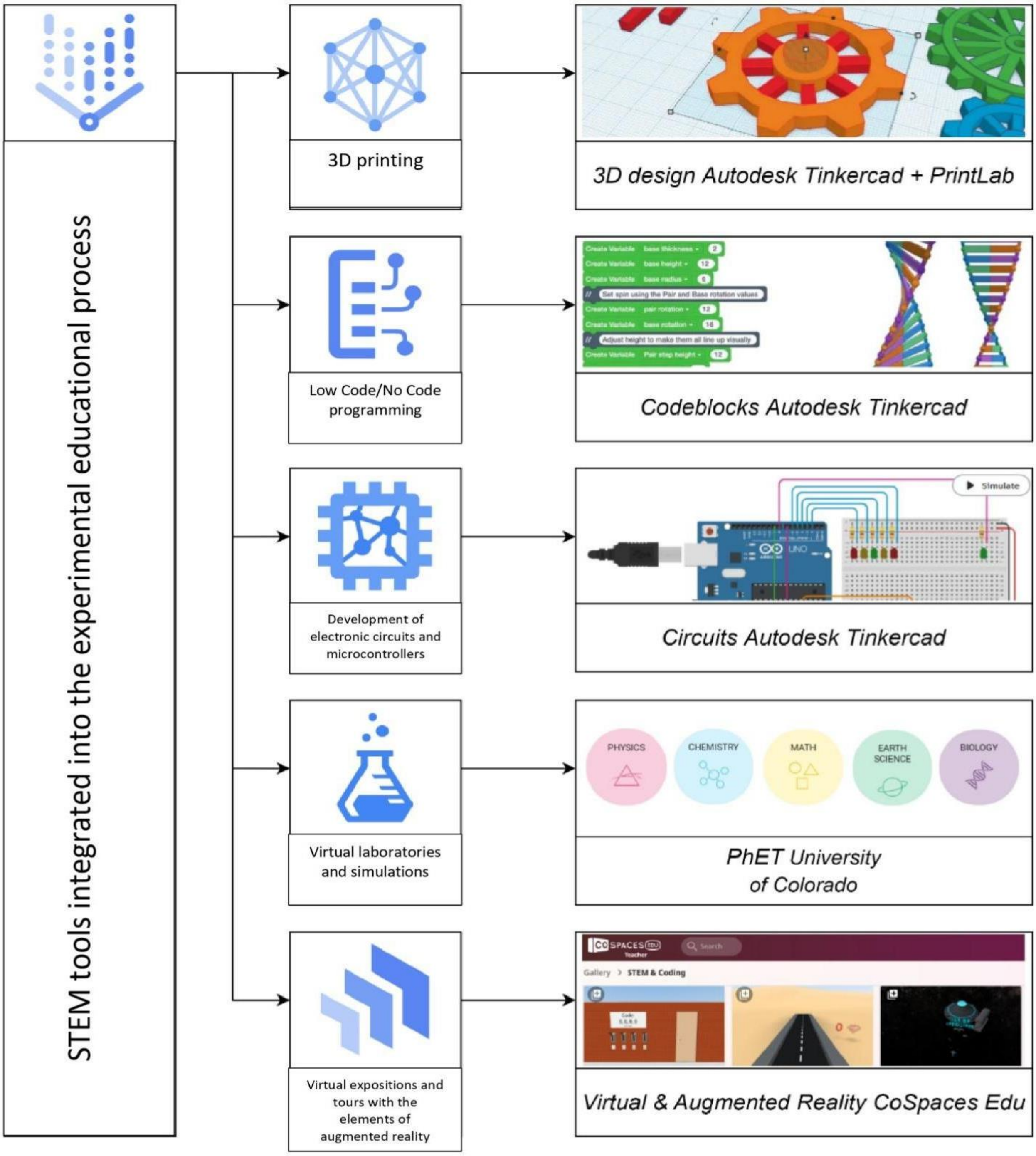

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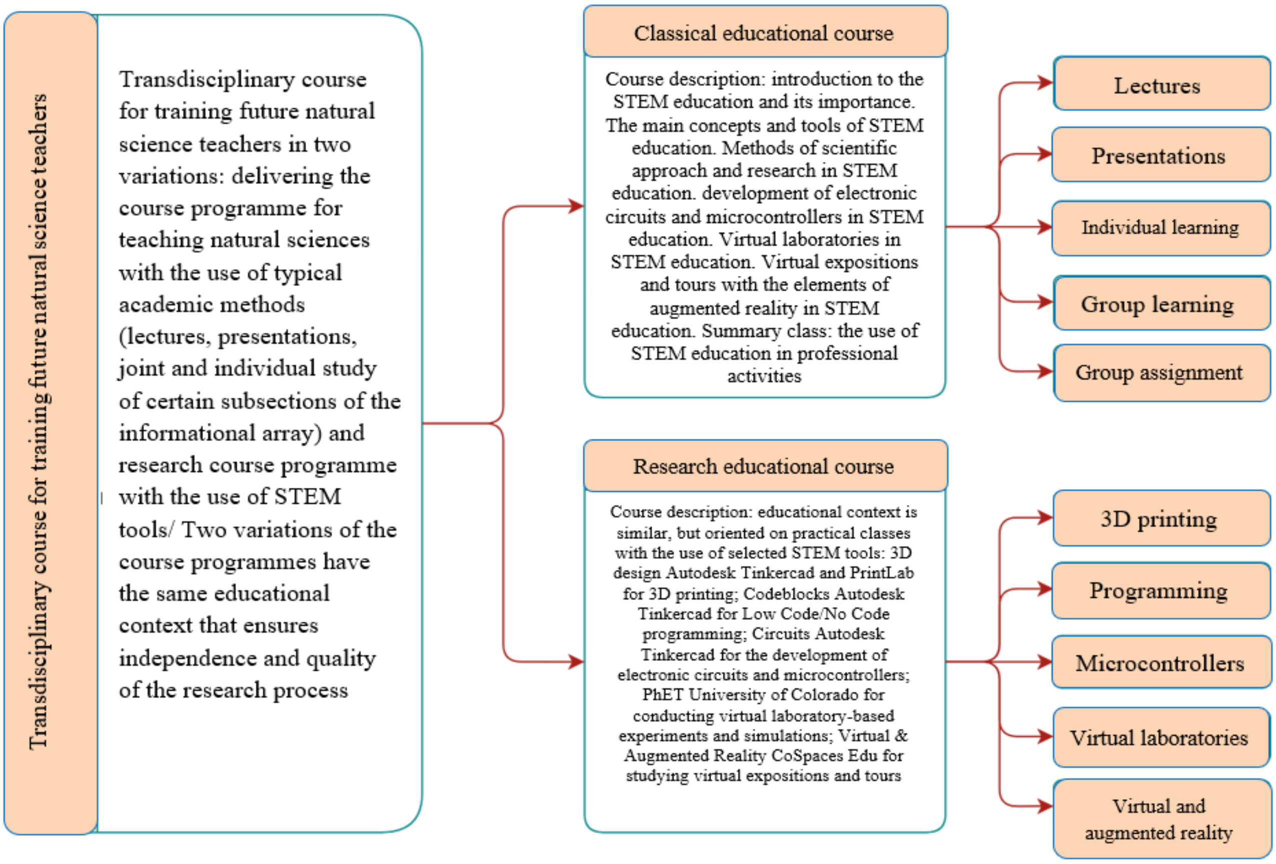
Figure 3. Transdisciplinary course for training future natural science teachers. The duration of the course is 1 academic semester



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Similar results of the repeated survey are given for students of the experimental subgroup (B) (Appendix B): there is a significantly higher level of readiness for the implementation of STEM tools in the educational process.

The obtained data of the correlative analysis of the results of the first and second phase of surveys (Figure 4) enable assessing the effectiveness of the used means and methods of raising awareness and readiness for the implementation and integration of STEM tools in the educational process in Ukraine and further professional activity of the studied group of future teachers — Figure 5.

We conclude that it is possible to achieve a high level of readiness of future natural science teachers for the integration of STEM tools in the educational process in Ukraine and in their further professional activities with the use of complete educational courses with subject and interdisciplinary practical classes. An integrated efficiency indicator is

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97%, which is 1.7 times more than the corresponding indicators of a short information campaign and 5.1 times more than the initial indicators before the educational influence.

Figure 4. Correlative analysis of the results of the first and second phase of surveys

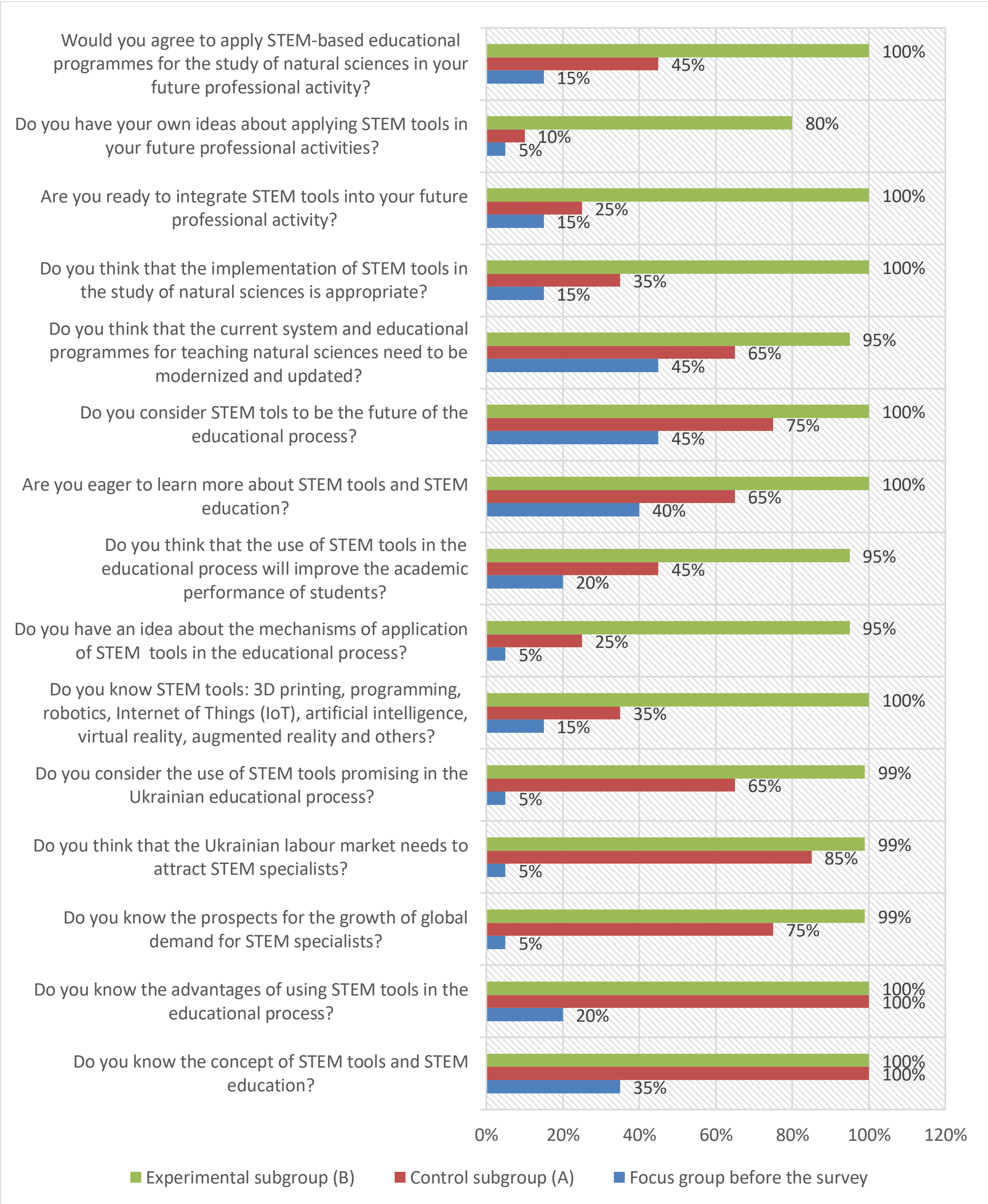

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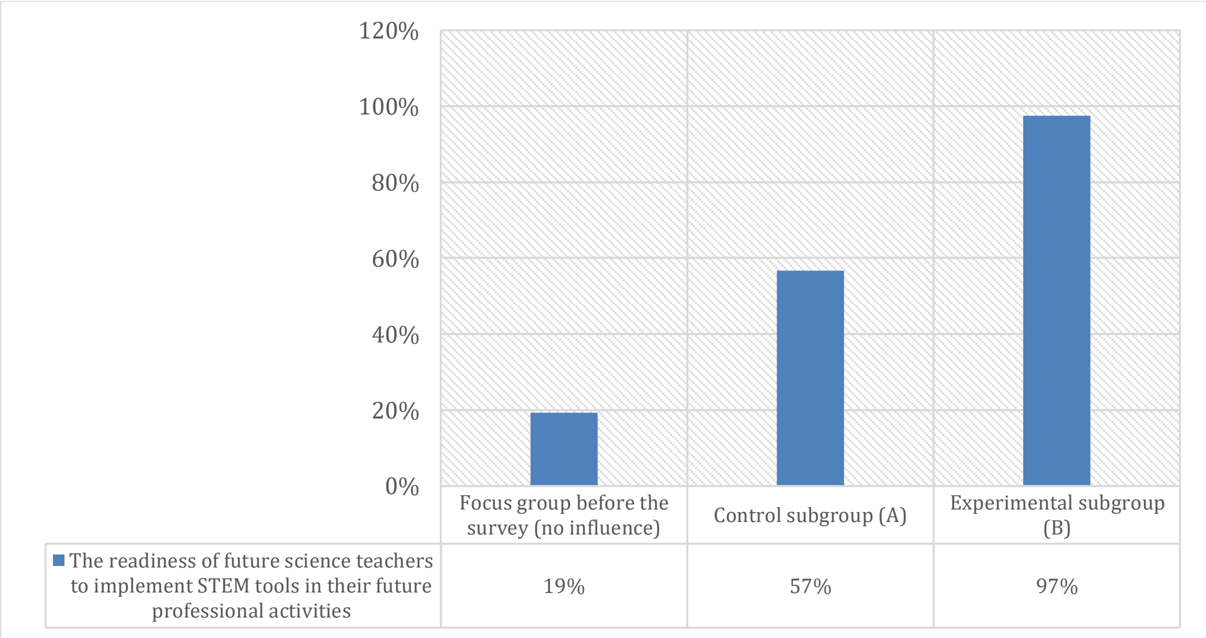
Figure 5. An integral indicator of the effectiveness of methods for improving the readiness of future natural science teachers to implement STEM tools in their future professional activities



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An accompanying survey was conducted among the students of the experimental subgroup (B) on the effectiveness of teaching the material of each of the STEM tools integrated into the educational course (Figure 3). The survey results showed the distribution of future teachers' preferences — Figure 6.

The majority of students in subgroup B preferred the PhET University of Colorado educational service (https://phet.colorado.edu/) – Appendix D.

The obtained results can be used as a basis for developing recommendations for optimizing the strategy of introducing STEM tools into the educational system of Ukraine with the aim of modernizing and innovating education.

In particular, it is advisable to introduce appropriate transdisciplinary courses (Figure 3) using STEM tools in Ukrainian universities for the training of future natural science teachers in view of the current conditions of the educational process in Ukraine and the world, with the physical absence of teachers and students in educational institutions. In particular, the STEM education service PhET University of Colorado

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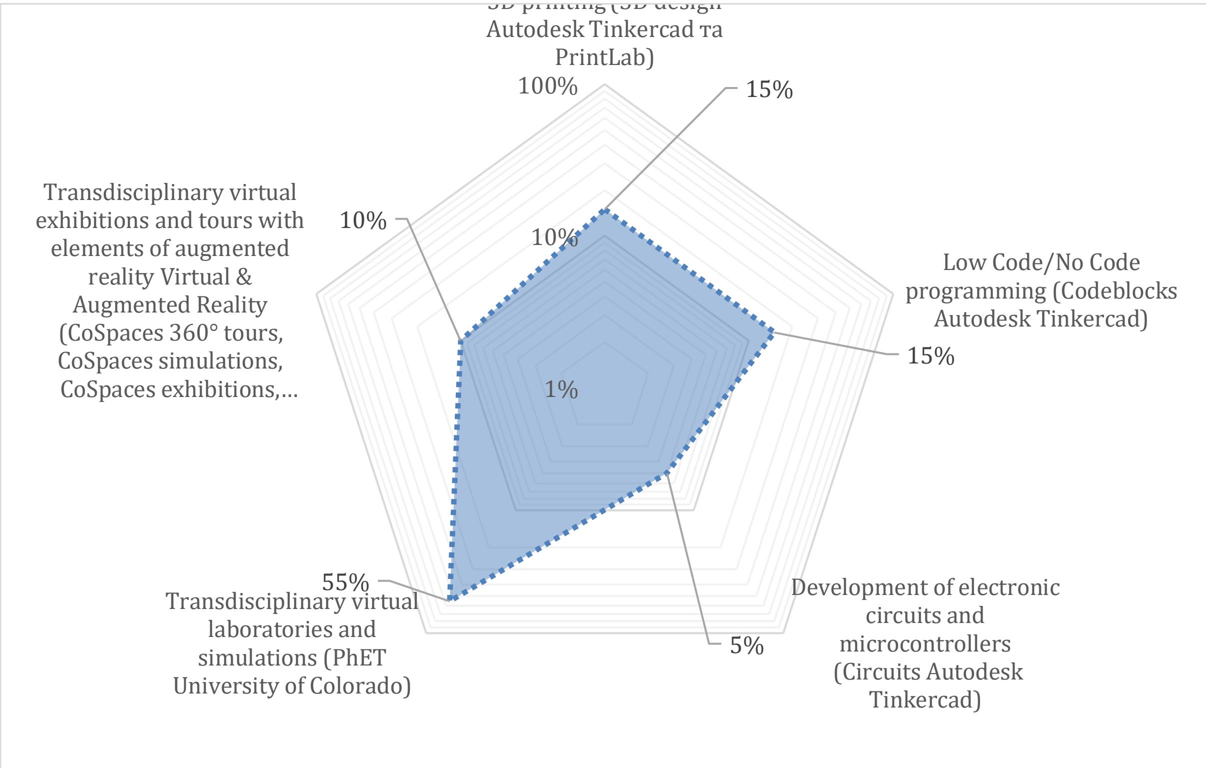
(https://phet.colorado.edu/) is the most adequate for these conditions (Figure 6, Appendix D).

Figure 6. Distribution of preferences of students from the experimental subgroup (B) regarding the effectiveness of teaching an educational course using various integrated STEM tools



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The study confirms that it is necessary to involve future teachers in active learning and interdisciplinary practical classes in order to develop their skills and abilities using STEM tools. It is necessary to support active training and development of skills and abilities of future science teachers using STEM technologies, as well as to develop and implement systemic solutions to support the development of STEM education in Ukraine in order to achieve strategic national interests in the modernization, innovation, and conceptualization of the Ukrainian education system.

4. Discussion

We will compare the obtained results with the studies which are the most relevant to the object of study and local conditions of Ukraine within the scope of this research.

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Valko and Osadchyi (2021) study the principles of the effective teacher training system for the use of STEM tools. At the same time, this study is more focused on specific methods and tools for the training of future teachers and offers specific methods to achieve the goal of improving the readiness of future teachers to implement STEM tools. Stepanyuk and Olendr (2019) focus on the analysis of the realities and prospects of training future natural science teachers in pedagogical universities of Ukraine. On the contrary, this study focuses on the effectiveness of practical courses with subject and interdisciplinary classes in order to increase the readiness of future teachers to integrate STEM tools into the educational process in Ukraine. The results of the study by Velychko et al. (2022) indicate the need to improve the qualifications of practicing teachers, use modern STEM tools, and promote participation in relevant educational programmes. In turn, this study recommends the introduction of full educational courses with subject and interdisciplinary practical classes to prepare future natural science teachers for the implementation of STEM tool in their professional activities.

Kastriti et al. (2022) study the issue of teaching natural sciences in preschool institutions using the STEM approach. In contrast, this study focuses on the readiness of future natural science teachers. Lukychova et al. (2022) pay more attention to the use of ICT in the context of STEM education, while this study focuses on the preparation of future natural science teachers for the integration of STEM tools in their professional activities. Budnyk (2019) emphasizes the innovative competence of the teacher, which is necessary for the effective implementation of STEM education. This study also draws attention to the need to prepare future teachers for the integration of STEM education into pedagogical practice. This study deals with the issues of training future teachers on using STEM tools, while Valko et al. (2020) focus on building a model of STEM education in the context of distance learning.

Kuzmenko et al. (2022) consider the integration of information and communication technologies into the educational process in order to improve the quality of education. At the same, this study examines the readiness of future teachers to implement STEM tools in their professional activities. In comparison with this study, which analyses future teachers' readiness for STEM education in Ukraine, the study of Mafugu et al. (2023) focuses on the perception of the STEM approach by future teachers. In comparison with the results of the study by Wardani et al. (2021), this study describes the degree of readiness of future

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teachers to use STEM tools in the educational process. Parmin et al. (2020) investigates the attitude of natural science teachers in Indonesia, while this study investigates the attitude of students of pedagogical universities in Ukraine to STEM education. Hackman et al. (2021) focus on secondary school natural science teachers in Liberia, while this study analyses the training of future natural science teachers in Ukraine to use STEM tools.

In general, all studies on the issue under research are aimed at exploring the STEM-based educational process and training future teachers to work with these tools. They differ in research objects (for example, students of higher education institutions, primary and secondary school teachers, natural science teachers, etc.), as well as research methodology and methods. For example, some studies are aimed at assessing the level of knowledge and skills of future STEM teachers, others — at analysing the impact of the use of STEM tools on the quality of education and interest in them. The studies can also cover various aspects of STEM education, for example, the use of information and communication technologies, problems of low diffusion of STEM tools, etc. However, all these studies have a common goal — improving the process of teaching STEM subjects and training future teachers to work with these tools.

Conclusions

-Relevance

The relevance of this study is that STEM education is becoming increasingly important in the context of the rapid technological development and current requirements of the labour market. Ukrainian education needs to be modernized and adapted to the current challenges, therefore research on the state of training of future teachers for the use of STEM tools is very important. The research can help to identify shortcomings and prospects in the training of future teachers. It also contributes to the improvement of the educational process in order to build the competencies necessary for the effective implementation of STEM tools in higher education. Besides, the research results can be used to develop programmes and methods for improving the level of training of future teachers for the use of STEM tools.

-Research findings

The results of research give grounds to draw the following conclusions:

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- students of the senior years majoring in natural sciences have little knowledge of STEM technologies and STEM education, therefore most of the surveyed future teachers are poorly prepared for the integration of these technologies in their professional activities, which may become an obstacle in the preparation of STEM specialists as the basis of national interests in the development of the technological field. One of the main reasons for low awareness is the lack of a consistent information campaign for the university students majoring in natural sciences on the education and training in STEM tools;

- students of the control subgroup (A) acquired more knowledge about STEM tools and their importance for the development of education and the technological field, but do not have sufficient skills and motivation to integrate STEM tools into their professional field; the survey revealed a redistribution of opinions on the reasons for the low diffusion of STEM technologies in the Ukrainian educational process, most students see the problem in systemic solutions, such as modernization of the educational process, state support and the national course, economic support, and direct state funding;

- the results of a repeated survey of the students of the experimental subgroup (B) show a greater readiness for the integration of STEM tools in the teaching of natural sciences, which is accompanied by an increase in motivation and a more structured vision of the systemic problems of the implementation of STEM technologies, in particular with the identification of the problems of the lack of state support in the coordination, as well as economic and material contexts;

- full educational courses with subject and interdisciplinary practical classes (integral effectiveness indicator 97%), that will have direct economic consequences for the entire economic and technological space of Ukraine are effective for achieving a high level of readiness of future natural science teachers for the integration of STEM tools in the educational process in Ukraine and their further professional activity;

- according to the results of the accompanying survey, students of the experimental subgroup (B) preferred virtual laboratories and simulations of the PhET University of Colorado STEM education service (https://phet.colorado.edu/) among the STEM tools used.

-Applications

The results of this study can be useful for the development of full educational courses with subject and interdisciplinary practical classes that will help teachers to develop the necessary skills and abilities in order to achieve strategic national interests in the modernization, innovation, and conceptualization of the education system in Ukraine. This research also gives grounds to develop teacher training programmes for the purpose of training highly qualified STEM specialists. In turn, this will contribute to the development of the economic and technological space of Ukraine. Moreover, the research results can be useful for the development of a state strategy in the field of STEM education and innovative development.

-Prospects for further research

The following directions can be considered for further development of research in the field of STEM education:

- development and implementation of innovative educational technologies using STEM tools in the educational process;
- analysis of the level of readiness of future teachers for the implementation of STEM tools in the educational process using a wider sample of students from different higher educational institutions;
- studying the impact of STEM education on enhancing students' motivation and activity in the process of learning natural sciences;
- studying the practical application of STEM tools in a real educational environment at different levels of education and in addition to research in the field of STEM education;
- analysis of the level of computer literacy and the use of electronic learning tools among future natural science teachers.

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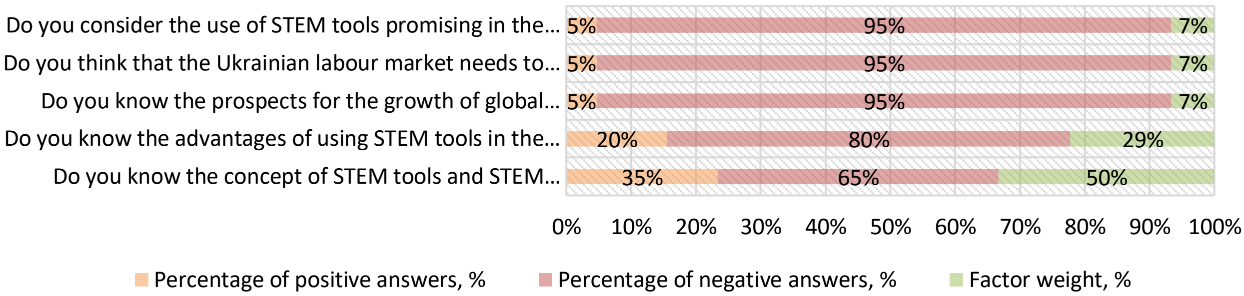
Appendix A.

Results of the first phase of the survey

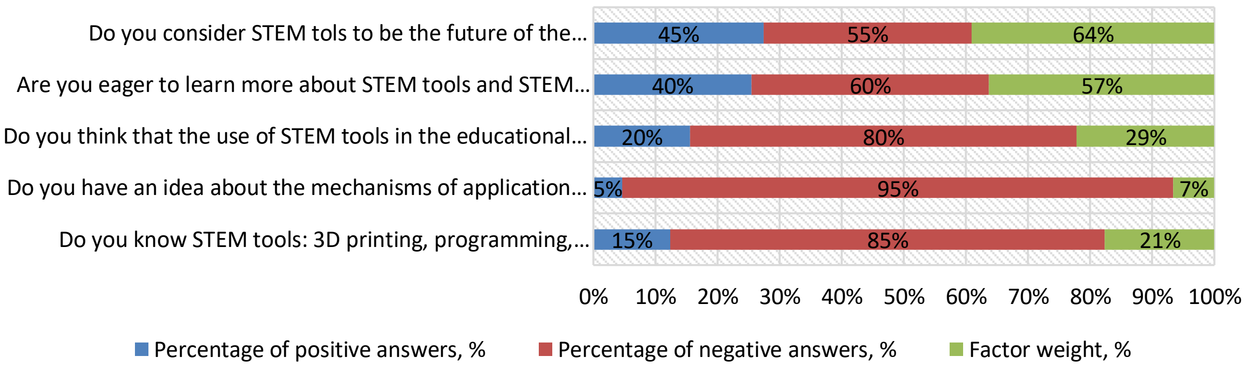
In accordance with the developed research procedure, the results of the first phase of the survey were obtained according to the logical blocks – Figures A.1 – A.2.

Figure A.1. Results of the first phase of the survey (information block)



Source: created by the author

Figure A.2. Results of the first phase of the survey (experimental block)



Source: created by the author

The obtained results show that the students of the senior year of natural sciences are mostly uninformed about STEM tools and STEM education. Moreover, the majority of interviewed future teachers are poorly informed about the potential of STEM tools and their usefulness in the development of the educational process and the preparation of STEM specialists as the basis of national interests in the development of the economic and technological field. De facto, the surveyed future natural science teachers are mostly not ready to integrate STEM tools in their further professional activities.

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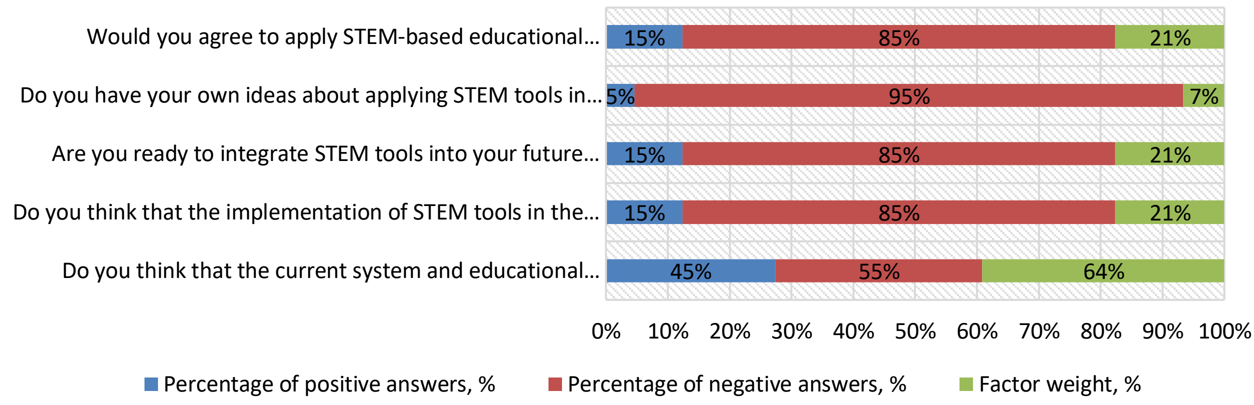
Figure A.3. Results of the first phase of the survey (practical block)



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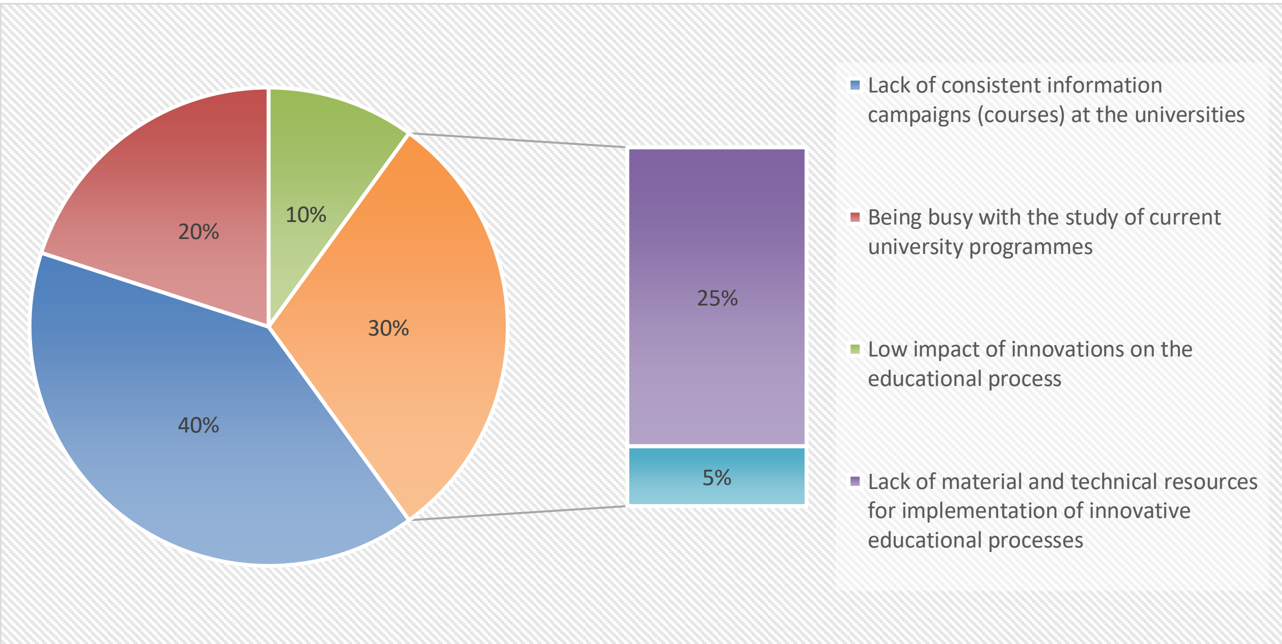
The surveyed students note the lack of a consistent information campaign at the higher education institutions that these learners undergo training and preparation among the main reasons for low awareness — Figure A.4.

Figure A.4. Analysis of the reasons for the low diffusion of STEM tools in the educational process in Ukraine according to the opinion of interviewed future natural science teachers



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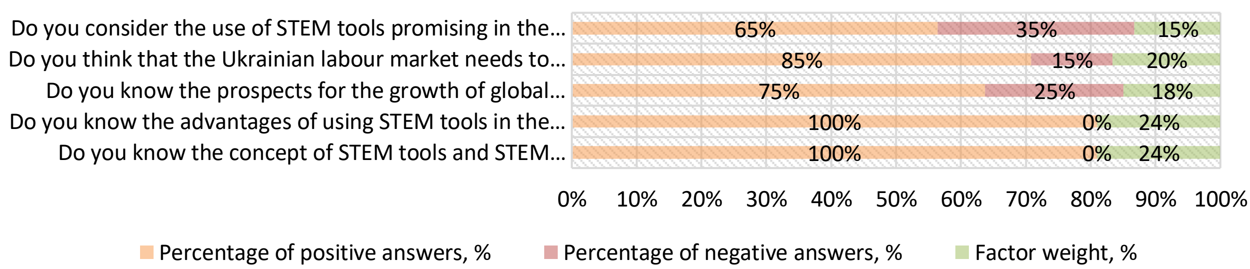
Although during the accompanying survey, representatives of the research environment note the systemic factors that shape the efficiency of STEM tools at the state level. However, the respondents do not consider this to be the main problem in the modernization and innovative development of the Ukrainian educational system.

Appendix B.

Results of the second phase of the survey for the control group

Results of the survey of the control group (A) – Figures B.1 – B.3.

Figure B.1. Results of the second phase of the survey for students of the control subgroup (A) (information block)



Source: created by the author

Figure B.2. Results of the second phase of the survey for students of the control subgroup (A) (research block)

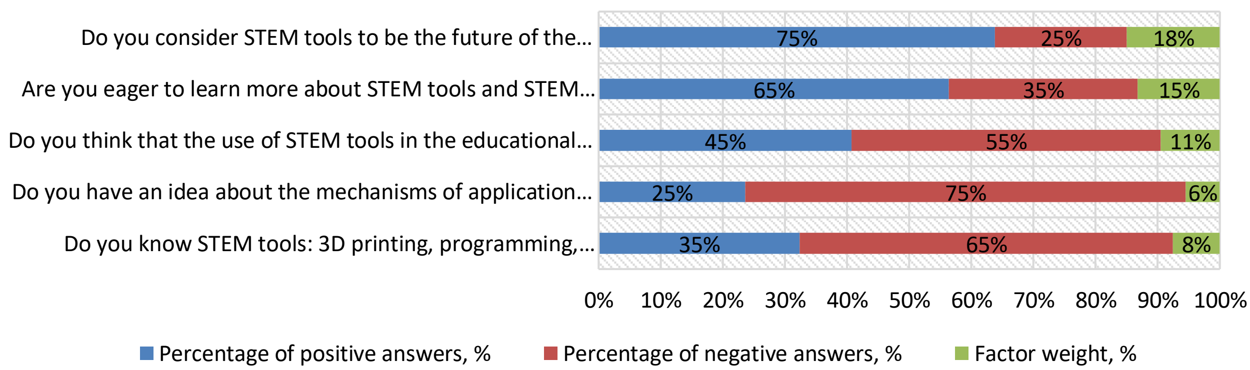


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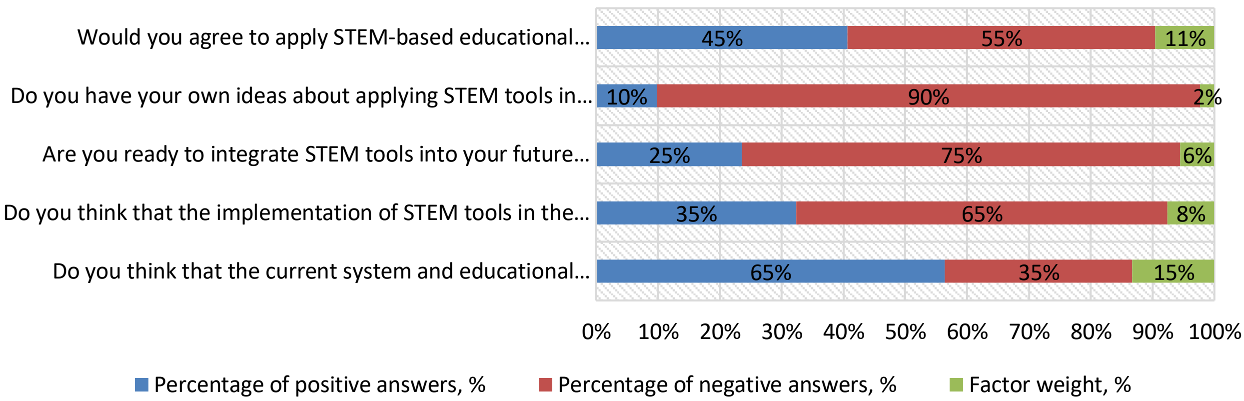
Figure B.3. Results of the second phase of the survey for students of the control subgroup (A) (practical block)



Source: created by the author

The percentage ratio of the opinions of students of the control subgroup (A) regarding the reasons for the low diffusion of STEM technologies in the Ukrainian educational process has also changed — Figure B.4.

In general, it is observed that students of the control subgroup (A) are already more aware of the potential of STEM tools and their importance for the development of education, as well as the economic and technological sphere. However, future teachers are not ready for the implementation and integration of STEM tools in their professional field in the absence of starting skills and appropriate motivation. At the same time, there is a redistribution of opinions regarding the reasons for the low diffusion of STEM tools in the educational process in Ukraine. After the appropriate information campaign, the majority of re-interviewed students see the problem of the development and integration of STEM education as systemic solutions, such as the need to modernize the educational process, systemic state support and the relevant national course, economic support, and direct state financing of the material and technical resources for the development of the STEM industry and the increasing number of STEM specialists.

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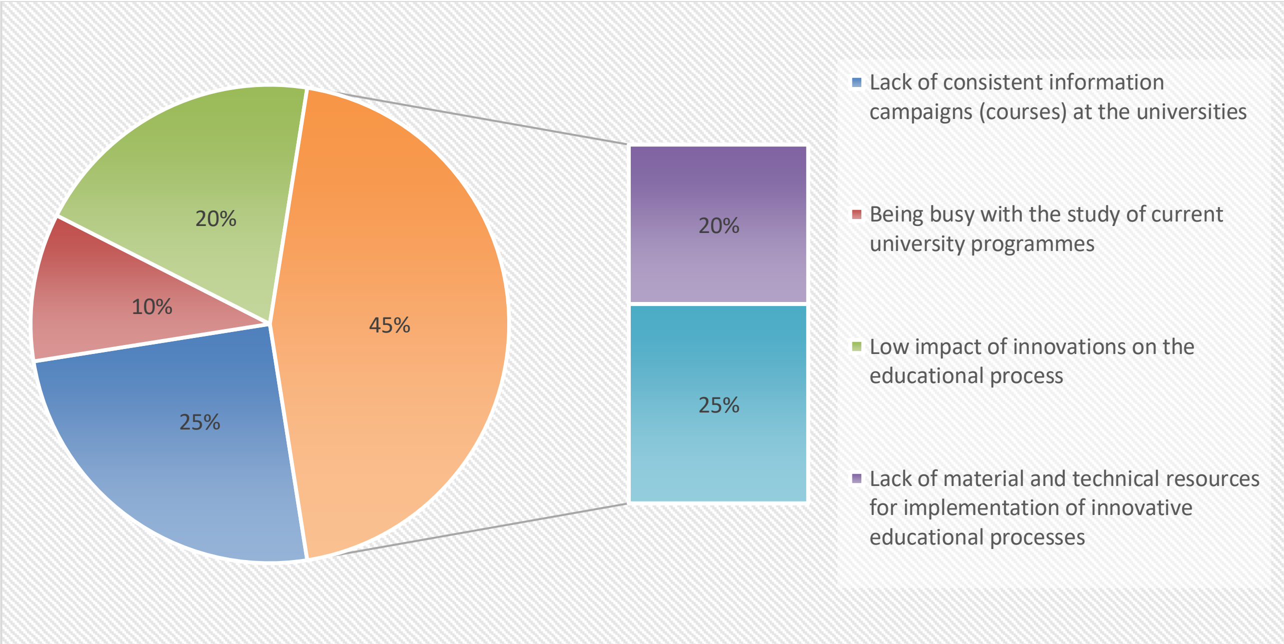
Figure B.4. Analysis of the reasons for the low diffusion of STEM tools in the educational process in Ukraine according to the students of the control subgroup (A) after a short information campaign on the prospects of using STEM tools in the educational process



Source: created by the author

Appendix C.

Results of the second phase of the survey for the experimental group

Results of the survey of the experimental group (B) – Figures C.1 – C.3.

Figure C.1. Results of the second phase of the survey for students of the experimental subgroup (B) (information block)

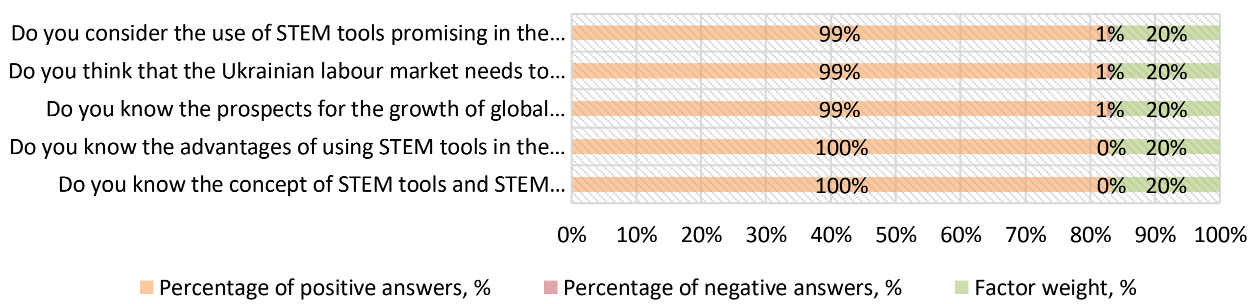


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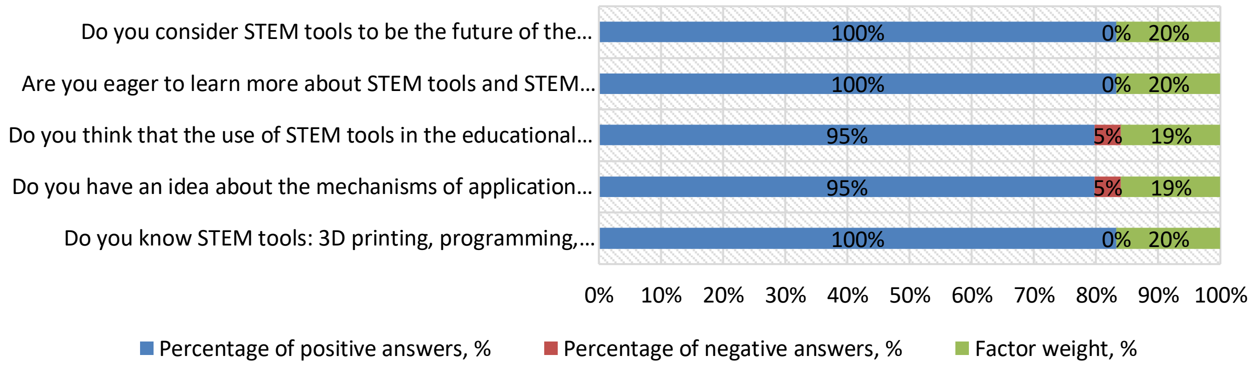
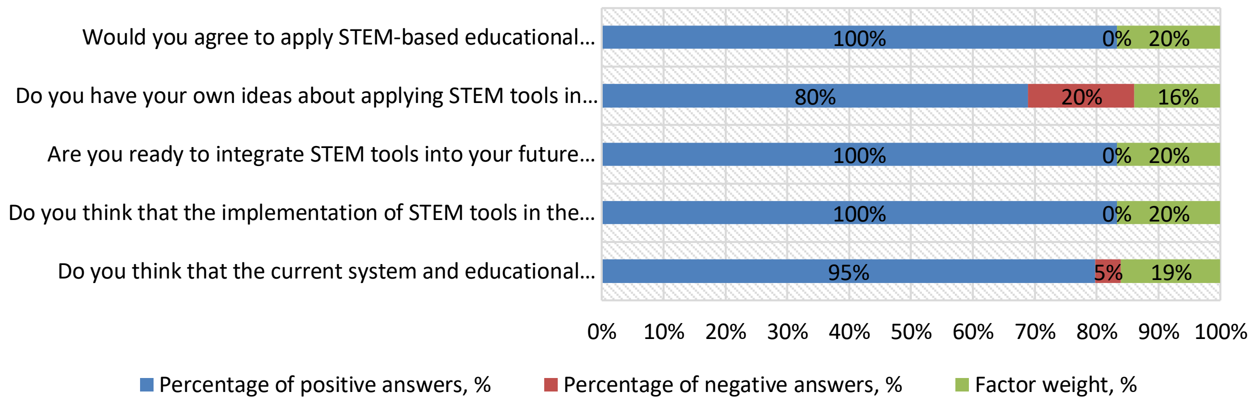
Figure C.2. Results of the second phase of the survey for students of the experimental subgroup (B) (research block)



Source: created by the author

Figure C.3. Results of the second phase of the survey for students of the experimental subgroup (B) (practical block)



Source: created by the author

The percentage distribution of the opinions of students of the experimental subgroup (B), in the second phase of the survey (accompanying survey) on the reasons that lead to a low level of implementation of STEM tools in the education system of Ukraine is also interesting — Figure C.4.

Future natural science teachers who have completed an experimental theoretical and practical course on the use of STEM tools in their further teaching have a more structured vision of the systemic issues of implementing STEM tools in the educational process in

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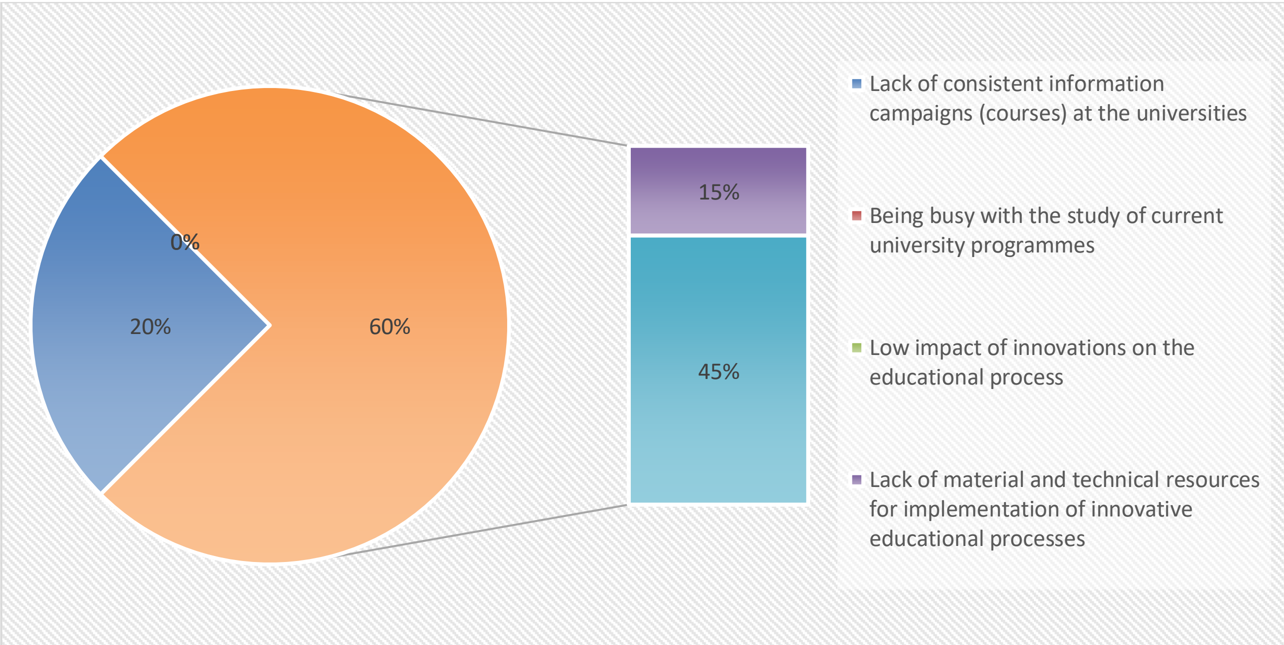
Ukraine, which is manifested in particular by the perception of insufficient support from the state, both in the coordination and in the economic and material context.

Figure C.4. Analysis of the reasons for the low diffusion of STEM tools in the Ukrainian educational process according to the students of the experimental subgroup (B) after completing a practical educational course on the prospects of using STEM tools in the educational process



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Appendix D.

Characteristics of the STEM education service PhET University of Colorado (https://phet.colorado.edu/)

The STEM education service *PhET University of Colorado* (https://phet.colorado.edu/) contains virtual laboratories and simulations of the academic qualification level — Figure D.1 – D.5.

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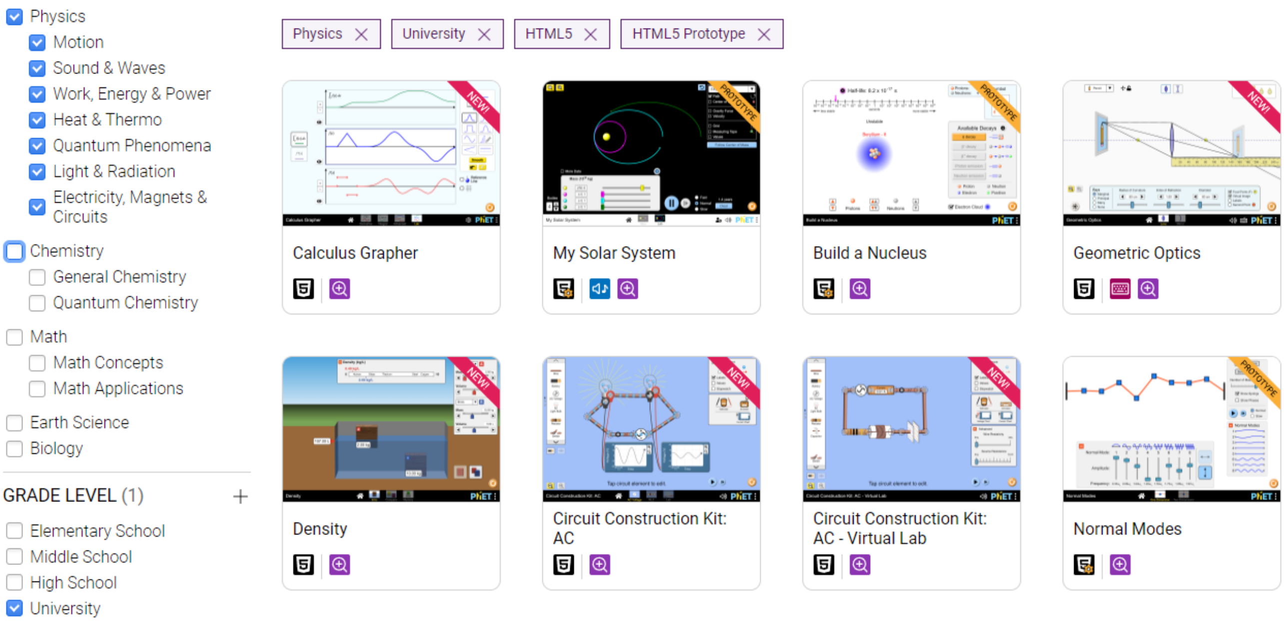
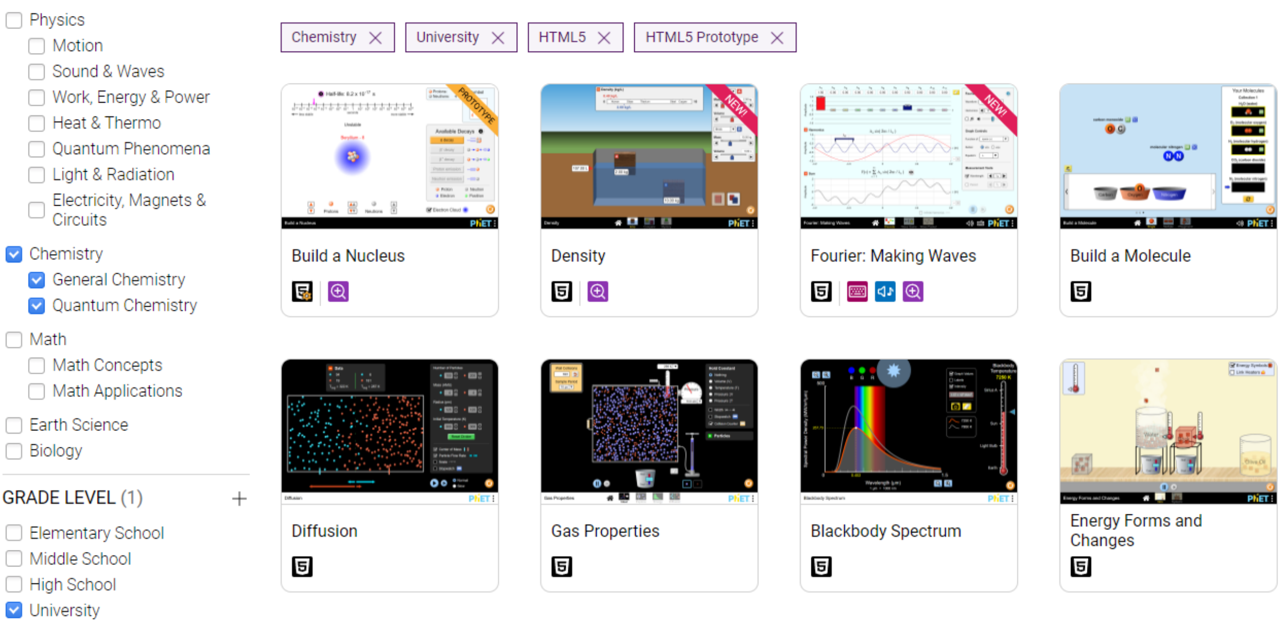
Figure D.1. Virtual laboratories and simulations of the STEM education service *PhET University of Colorado* (https://phet.colorado.edu/) for studying Physics



Source: PhET University of Colorado (https://phet.colorado.edu/)

Figure D.2. Virtual laboratories and simulations of the STEM education service *PhET University of Colorado* (https://phet.colorado.edu/) for studying Chemistry



Source: PhET University of Colorado (https://phet.colorado.edu/)

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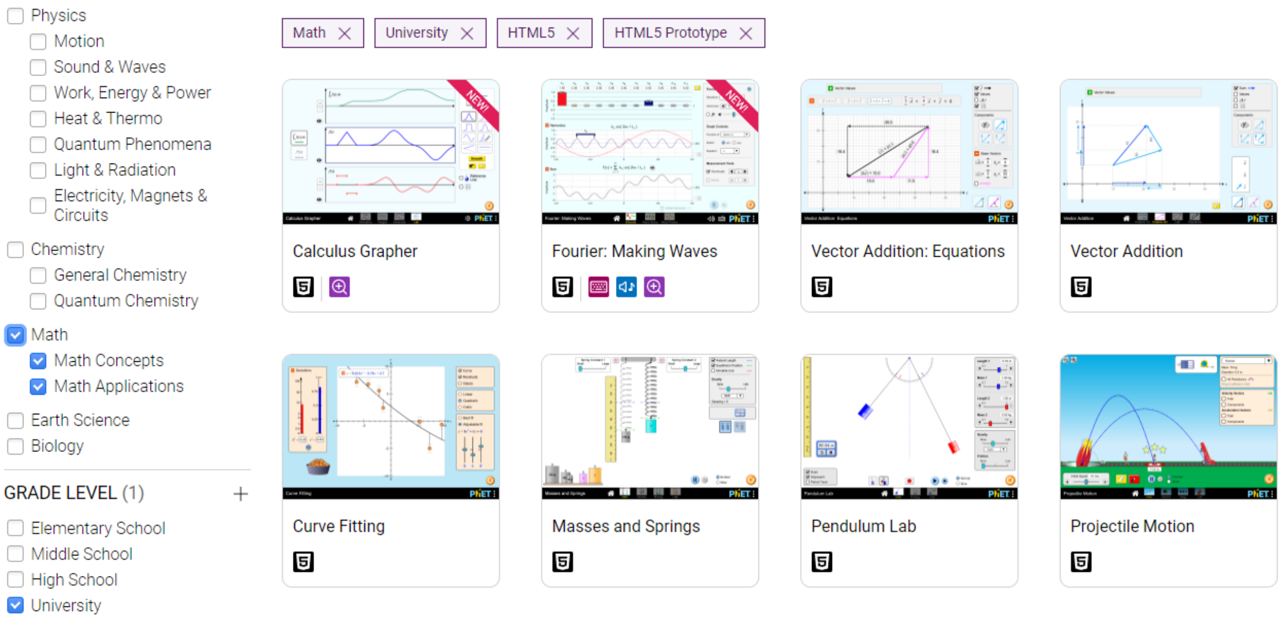
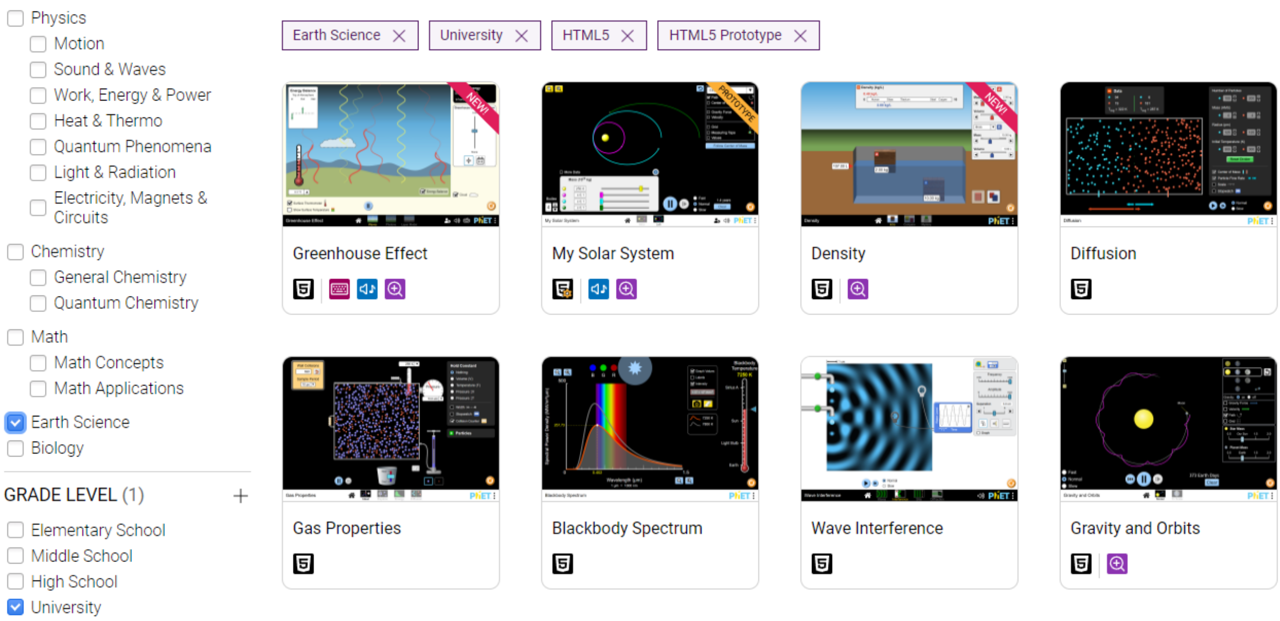
Figure D.3. Virtual laboratories and simulations of the STEM education service *PhET University of Colorado* (https://phet.colorado.edu/) for studying Mathematics



Source: PhET University of Colorado (https://phet.colorado.edu/)

Figure D.4. Virtual laboratories and simulations of the STEM education service *PhET University of Colorado* (https://phet.colorado.edu/) for General Natural Sciences



Source: PhET University of Colorado (https://phet.colorado.edu/)

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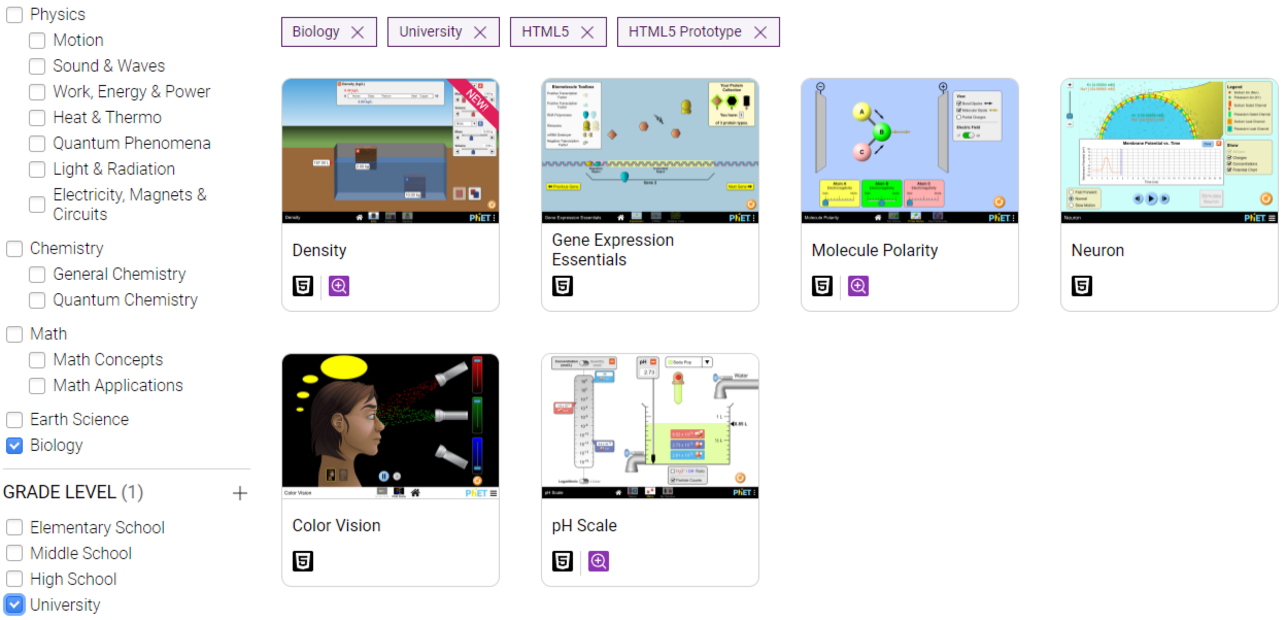
Figure D.4. Virtual laboratories and simulations of the STEM education service *PhET University of Colorado* (https://phet.colorado.edu/) for studying Biology



Source: PhET University of Colorado (https://phet.colorado.edu/)