International Journal of Research in E-learning
Vol. 9 (2), 2023, pp. 1–25

DOI 10.31261/IJREL.2023.9.2.02

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# The Use of Digital Technologies in Education: The Case of Physics Learning

## Abstract

The article reveals the trends in the use of digital technologies in teaching physics by summarizing scientific results over the past 20 years. To solve the problem, a bibliographic analysis of the sources of the scientometric database of the WOS was used with the involvement of the computer tool VOSviewer (for the construction and visualization of bibliographic data) as of June 2023. The tool was used to analyse publications by keywords (a network of connections is built on the basis of all keywords of given publications). Networks of connections of keywords were built according to the queries: “physics learning”, “physics education”, “physics teaching” and “technologies”, as well as “digital technologies in teaching physics”, “physics application”, “mobile physics learning”, “virtual physics laboratory", "digital physics laboratory", "virtual reality & physics", "augmented reality & physics". The situation of the use of digital technologies in teaching physics is characterized by four aspects (general, technological, educational-motivational, and educational-organizational). Modern trends in teaching physics are singled out: the use of environments where simulation, modelling, visualization, virtualization of physical processes, etc. are possible. The increasing popularity of virtual, augmented, and mixed reality tools; use of mobile applications for learning physics; using artificial intelligence to teach physics; organization of an educational environment based on mobile or online learning, where active learning methods are determined to be appropriate. The importance of developing young people's intellectual skills (computational skills, algorithmic thinking skills, modelling processes, etc.) and visual thinking for the successful mastery of various sections of physics has been confirmed. The demand for integration links between natural sciences, mathematics, engineering, and digital technologies for STEM education has been monitored. Recommendations for the training of physics teachers have been formulated.

K e y w o r d s: digital technologies; teaching physics; learning physics; physics education; physics teacher; teacher training; professional preparation; digital technology in education; higher education

The development of digital technologies has had a significant impact on society as a whole and on the scientific industry in particular. Computer tools are in demand in mathematics (Semenikhina et al., 2019; Astafieva et al., 2019; Semenikhina & Drushliak, 2015), computer science (Yurchenko et al., 2021), etc. Such tools can be either narrowly specialized (for solving a specific class of problems, for example, in mathematics, statistical data processing programs (for example, Statistica), or powerful universal programs that have digital tools for processing numerical data (for example, table processors like MS Excel), modelling of processes (for example, virtual laboratories like Proteus), programming of solutions of classes of applied problems (for example, programming environments like Eclipse IDE / IntelliJ IDEA or systems of computer mathematics like Maple). The types of tools used by scientists are also different; not only specialized software of the industry but also cloud services (Google Apps, Azure, Canva), mobile applications (WolframAlpha, CamScanner, Science Explorer, Graphical Analysis), digital or sensors on mobile devices (Proximity Sensor, Accelerometer, Light Sensor, Gyroscope Sensor, Vernier), etc.

### Problem of Research

Learning physics is not a trivial task. This science has always been hard to understand (Hsiao et al., 2023). Awareness and assimilation of physical concepts and processes, which are not obvious, require significant intellectual efforts from students (thinking, comparing, looking for analogies, critically evaluating, etc.). Therefore, physics teachers are constantly searching for new approaches, techniques, and methods that would interest students in physics and help students master complex material (Izadi et al., 2022). Among such approaches, the digital one stands out (Jugembayeva & Murzagaliyeva, 2023). In particular, demonstration video materials of Internet resources and presentation materials that improve the visual support of physics classes are quite popular in Ukraine (Semenikhina et al., 2020), less popular is the involvement of physical guidance software. World practices of using DT (digital technologies) in teaching physics with the development of DT are also constantly changing. The use of DT is presented in numerous publications of the results of educational research, which, unfortunately, are not summarized as existing successful pedagogical experiences.

### Research Focus

The purpose of the article is to characterize the situation of the use of digital technologies in teaching physics on the basis of bibliographic analysis of scientific and methodological works.

## Methodology of research

### General Background of Research

Publications related to the use of digital technologies in teaching physics and indexed by the Web of Science scientometric database for the years 2005–2023 became the basis of the research. The search was conducted in the Web of Science database on June 25, 2023.

### Instrument and Procedures

The tools of bibliographic analysis were the Web of Science database itself and the freely distributed tool VOSviewer (https://www.cwts.nl). The tool is designed for building and visualizing bibliographic data from various database sources (Web of Science, Scopus, Dimensions, CrossRef, Medline). The developers of the tool provided the possibility to process citations, bibliographic links, joint citations, and co-authorship. The tool was used to analyse publications by keywords (a network of connections is built on the basis of all keywords of given publications). You can limit the network by setting, in particular, a minimum number of connections. The network also breaks the words into clusters. Each cluster has a different color and consists of circles (or words) of different sizes. Size is determined by frequency. The larger the word, the more often the word is used in research (Al Husaeni & Nandiyanto, 2022). The type of analysis in VOSviewer is Co-occurrence. Analysis unit are all keywords. The selection limit (minimum number of keywords found) was determined depending on the number of found works and keywords in general. As a result of using the VOSviewer tool, networks of connections of keywords were built for various queries. Based on the identified relationships between keywords in the publications, a qualitative analysis of trends was carried out and conclusions were drawn.

The problem of the study has defined the criteria for choosing keywords belonging to the field of physics education and the field of information technology. The search was based on keywords for publications from the Web of Science database (we proceed from the fact that the authors, exploring the problem, correctly select keywords for their research). When the number of keyword meetings was relatively small (up to 100 search results), the annotations' texts were also searched since the abstract describes in more detail the direction of scientific research and the results obtained.

We have identified several words that have become search tools. By the criterion of belonging to the field of education, we took the words: education, learning, teaching, and laboratory. Words like "university, secondary education, student, distance \ blended learning" were not considered due to a narrower focus. By the criterion of belonging to the IT industry, we took the words: technology, digital technologies, applications, virtual, and mobile. The terms "cloud\mobile technologies" are excluded because they are included in digital technologies. The word "software" is also excluded, as online services and mobile applications are becoming increasingly popular today. The word "virtual" is involved because today, IT companies present developments in virtual reality that can be used in teaching physics.

In the WOS database, we searched as follows: the search field entered the word of our choice, which by the type of request was characterized as the keyword of the publication. The result of the search was the set of publications that include this word in their list of keywords. The number of publications was limited, and we took into account publications over the past 20 years. If the total number of publications was too small, we chose the search among the abstracts of the WOS database publications.

To identify general trends, we searched the annotations for the words "physic education" and "technology" or "physic learning" and "technology" or "physic teaching" and "technology". The words "physics and technology" were obligatory in the abstracts, and the words education, training, teaching could meet either all together, or at least one of them. In this way, we researched all publications that presented physics education and technology.

## Results of research

Since we investigated trends in the use of digital technologies in teaching physics, the following words were used to organize the bibliographic analysis: "physics learning", "physics education", "physics teaching" and "technologies", as well as "digital technologies in teaching physics", "physics application", "mobile physics learning", "virtual physics laboratory", "digital physics laboratory", "virtual reality & physics", "augmented reality & physics". Below are the results of processing requests.

Search by words "physics learning"

A search for the words "physics learning" revealed 7713 keywords, among which 55 words were found that were mentioned at least 25 times. The network of connections indicates (Figure 1) the presence of three clusters: physical education (science, knowledge, presentation, motivation, instructions, active learning, simulations); physics (mathematics, education, training); model (algorithms, design, computer modelling, simulation, optimization, etc.).

Search by words "physics learning" and "technologies"

A search for the words "physics learning" and "technologies" revealed a total of 435 keywords. 11 of them had 5 or more repetitions. Network analysis (Figure 2) revealed three similar clusters: physical education (e-learning, enhanced learning technologies); educational technologies (learning); physics (science, technology).

Search by words "physics education" and "technologies"

Searching for the words "physics education" and "technologies" revealed 448 keywords, 10 of which were repeated at least 5 times. The constructed network (Figure 3) shows three clusters: physics (mathematics, education, simulations); technologies (science, educational research in physics); physical education (educational technologies, engineering education).

Search by words "physics teaching" and "technologies"

A search for the words "physics teaching" and "technologies" revealed 354 keywords, of which 18 keywords appeared in the publications more than three times. The constructed network (Figure 4) shows the presence of four clusters by directions: physics teaching, physics, technologies, and training.

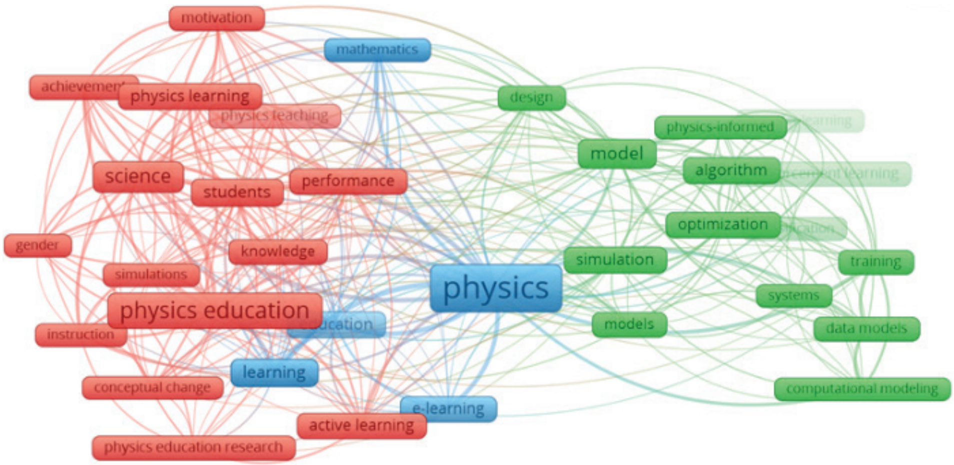


*Figure 1.* Network for «physics learning»

Source: Own work.


*Figure 2.* Network for «physics learning» & «technologies»

Source: Own work.

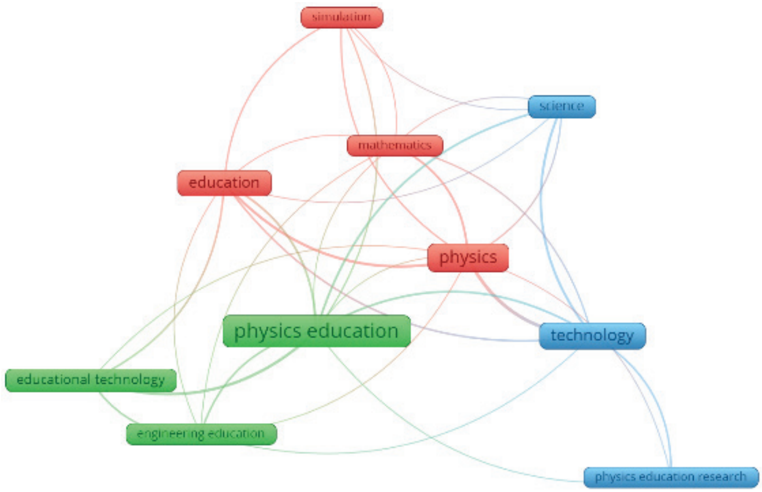


*Figure 3.* Network for «physics education» & «technologies»

Source: Own work.

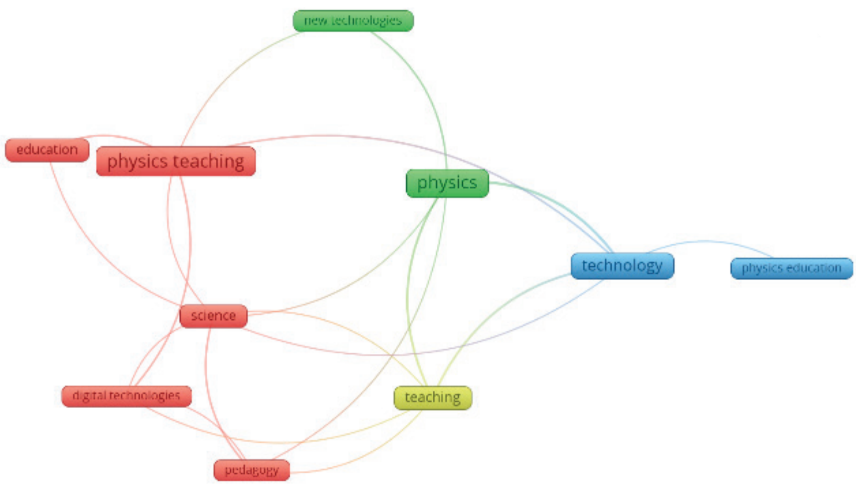


*Figure 4.* Network for «physics teaching» & «technologies»

Source: Own work.

A generalized search using the keywords "physics learning" and "technologies" or "physics education" and "technologies" or "physics teaching" and "technologies" in the Web of Science system shows that the vast majority of materials relate to educational research (1,813 or 41%) and educational scientific research (873 or 20%). We also note the presence of such areas as Engineering electrical Electronic (354 or 8%), Computer Science Interdisciplinary Applications (328 or 7%), and Computer Science Information Systems (302 or 7%), which indicates the popularity of the use of computer science in engineering and the development of applications for interdisciplinary programs.

Search by words “Digital technologies in physics teaching”

A search for the words “digital technologies in teaching physics” revealed a network of keywords (Figure 5) divided into seven main clusters: education, technology, students, physics, digital technologies, science, and teaching. In total, 69 (out of 1,718) unique keywords that appear in 5 or more publications became interconnected. The dynamics of the number of publications and the most used keywords in different periods are interesting (Table 1). Thus, in 1995–1999, the number of publications on the use of DT in teaching physics (Web of Science database) was low and amounted to 5, and unique keywords – 9, including system, information, teaching-file, interactive multimedia, world-wide-web, training, networks, internet, media imaging. Data for subsequent years are presented in the table (Table 1).

Table 1
*Data on publications upon request “Digital technologies in teaching physics”, 2005-2023*

| Years | Number of works | Number of keywords in works | | Keywords that were used most often |
|---|---|---|---|---|
| | | Generally | The most popular | |
| 2005–2009 | 20 | 98 | 9 | Computer, physics, curriculum, secondary education, teaching/learning strategies, applications in subject areas, agent, XML, e-learning |
| 2010–2014 | 46 | 196 | 13 | Education, higher education, technology, knowledge, inquiry, physics, teaching, framework, ICT, design, model, science teachers |
| 2015–2019 | 187 | 734 | 15 | Technology, physics, education, teachers, ICT, learning, physics education, motivation, design, science, mobile learning, students, pedagogical content knowledge, social media, physical education |
| 2020–2023 | 194 | 919 | 21 | Students, education, technology, motivation, information, digital technologies/technology, performance, higher education, online learning, feedback, classroom, knowledge, science, teaching, pedagogical content knowledge, pedagogy, education technology, model, impact |

Source: Own work.

The selection of publications for the years 2020–2023 divides them into three clusters: education, physics education, and technology.

Search by words “physics” and “digital technologies”

A search using the words “physics” and “digital technologies” revealed 28 publications from 2006 to 2023. In half of the cases, their subject concerns the educational field (Education Educational Research – 43%, Education Scientific Disciplines – 7%). A search for the same words in the abstracts revealed 981 sources, starting from 1990, and as of 2019, an average of 80 of them. Most of the publications relate to various sections of physics, but more than 17% relate to education (Education Educational Research – 12%, Education Scientific Disciplines – 5.6%).

Search by words “Physics application”

A search using the keywords “Physics application” revealed 208 publications. The total number of keywords is 1984, of which 37 words have 5 or more repetitions. The constructed network (Figure 6) revealed 6 clusters, of which the main ones are: application (simulation, education, etc.), physics (algorithms, visualization), and engineering (simulations, machine learning). A search for the words “Physics application” among the annotations revealed 62,500 resources.

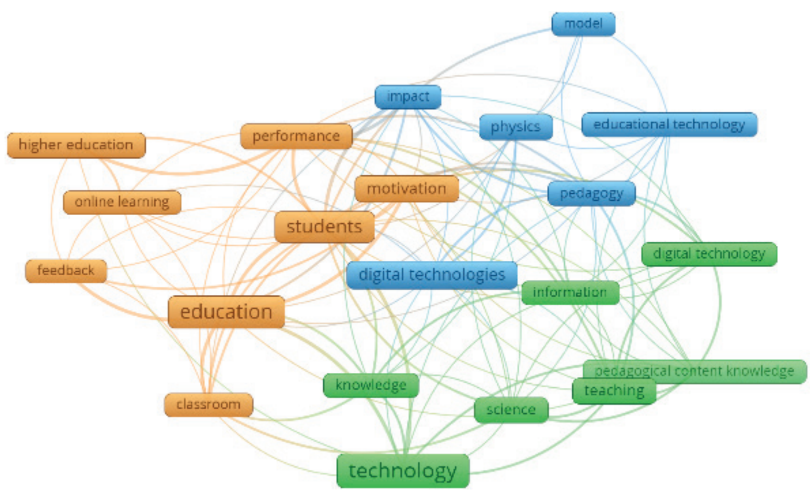


*Figure 5.* Network for «Digital technologies & teaching physics»

Source: Own work.

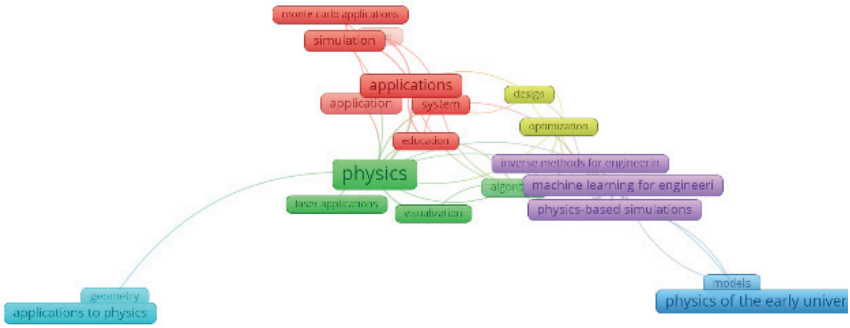


*Figure 6.* Network for «Physics application»

Source: Own work.

With the "education" specification, there are 822 results in the system, which are also presented in various sections of physics, which indicates the prevalence of such applications. The majority relate to the field of education (319 and 203 publications, which is 64%).

Search by words "application to physics"

A search for the word "application to physics" revealed 35 publications. At the same time, 13 words were found 3 or more times. Analysis of the network (Figure 7) shows that mathematical transformations, differential equations, geometry, and numerical fields are relevant here.

Search by words "physics learning mobile"

A search for the words "physics learning mobile" revealed 37 publications. The total number of keywords is 206. Among the keywords, 14 words are mentioned 3 or more times. The constructed network (Figure 8) revealed four clusters related to the teaching of physics and which proved not only the relevance of mobile but also mixed and e-learning, as well as means of augmented reality and guided experiments. A search in the abstracts of publications using the words "physics learning mobile" revealed 236 items, of which more than 60% are related to education (Education Educational Research – 42%, Education Scientific Disciplines – 20%).

Search by words "virtual physics laboratory"

A search among the abstracts using the specified keywords revealed about 1109 publications for the period since 2005, in which almost half of the scientific results are related to education: Education Educational Research – 25%, Education Scientific Disciplines – 19%. Searching for the keywords "virtual physics laboratory" found 29 publications since 2007. They recorded 199 keywords, of which 17 words occur more than twice. The network distinguishes clusters such as virtual physics laboratory, virtual experiment, virtual laboratory, and simulation.

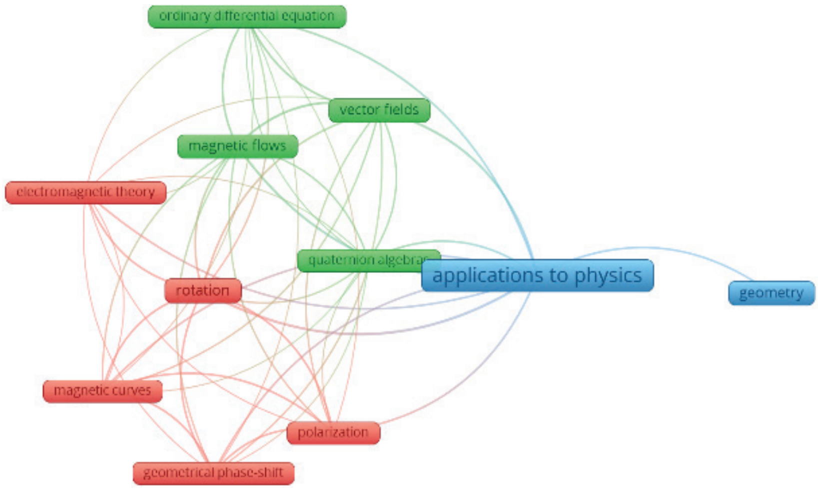


*Figure 7.* Network for «application to physics»

S o u r c e: Own work.

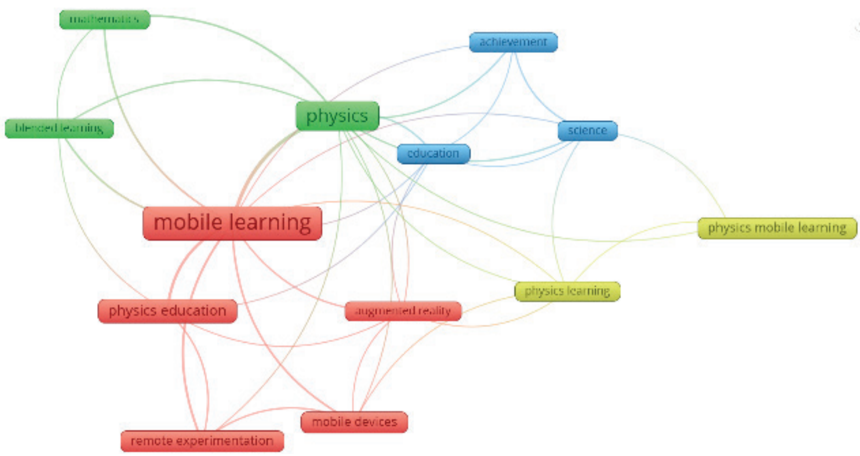


*Figure 8.* Network for «Physics learning mobile»

S o u r c e: Own work.

Search by words “digital physics laboratory”

A search among the abstracts using the specified keywords revealed more than 300 publications for 2005-2023, in which almost half of the scientific results are related to education; Education Scientific Disciplines – 16%, Education Educational Research – 11%. If you search among the keywords, only 3 results were found, which have a total of 10 keywords, some of which form a network. Searching for the words “digital laboratory” among the keywords revealed more publications – 382, which form a set of 2308 keywords. If we select those of them that occur 10 or more times, we will get a network, which forms three clusters such as education, laboratories, and systems.

Search by words “virtual reality & physics”

A search for the words “virtual reality & physics” among the publications revealed 97 sources, which together formed a set with 442 keywords. Building a network of these words (Figure 9), which had 5 or more repetitions, forms five clusters such as virtual reality (simulation, engineering), physics, physical education, physical modelling, and physical simulations. A search in the annotations for these words yields more than 500 sources, that is Education Educational Research – 12%, Education Scientific Disciplines – 8%.

Search by words “augmented reality & physics”

Searching for the words “augmented reality & physics” yields 55 publications. They form a cloud of 249 keywords, of which 11 occur 4 or more times. The network of words (Figure 10) forms two clusters: physical education and design, and architecture. If we analyse the topics of the works that have the words mentioned in the abstracts, then almost half of them are research in education that is Education Educational Research – 23%, Education Scientific Disciplines – 16%. A search in the database among the annotations using the words “augmented reality & physics” revealed publications related to education: education educational research – 33%, education scientific disciplines – 18%.

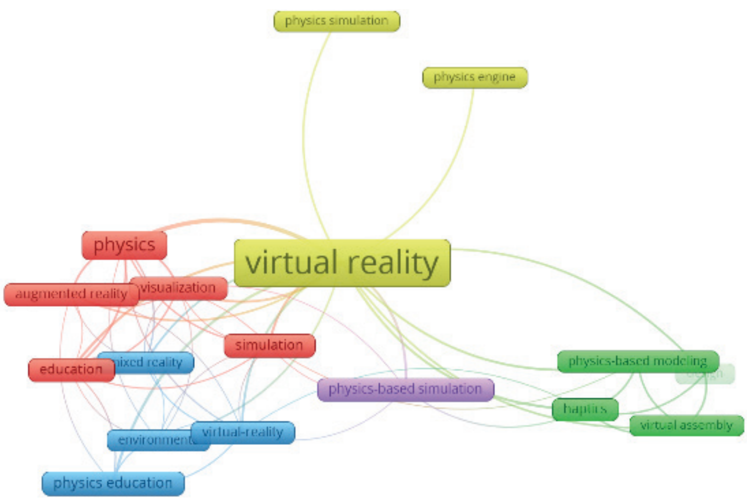


*Figure 9.* Network for «virtual reality & physics»

Source: Own work.

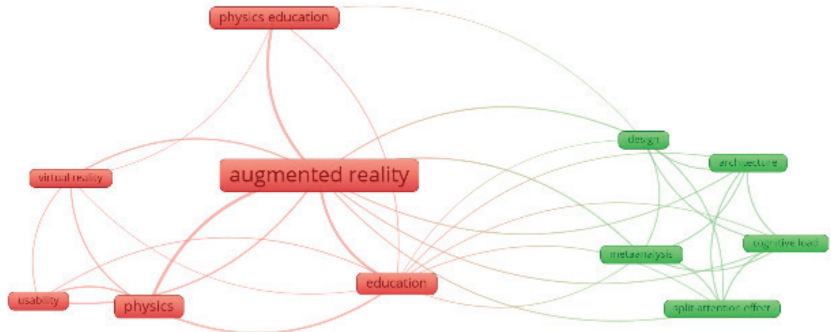


*Figure 10.* Network for «augmented reality & physics»

Source: Own work.

These were the quantitative results of the bibliographic analysis. Let's move on to their qualitative analysis.

The network of connections according to the words "physics learning" proves that the cluster that characterizes "physics education" connects not only scientific knowledge but also active learning based on research, demonstrations, models, simulation of processes, etc. The second largest cluster "physics" connects physics with mathematics and learning, including electronics. The third cluster indicates close connections with algorithms, design, computer modelling, simulation, etc. The generalization of network connections proves that the teaching of physics today by scientists is connected not only with motivated learning but also with mathematical and informatics education, which includes algorithmic thinking and active modelling of physical processes.

The network of connections for the words "physics learning" and "technologies" revealed connections between three clusters ("physics education", "educational technologies" and "physics"). The connections confirm the relevance of certain educational technologies in teaching physics such as electronic learning technologies and technologies of active and advanced learning.

The network of connections between the words "physics education" and "technologies" showed three leading clusters ("physics", "technology" and "physics education") that connect educational technology, engineering and mathematics education, physical science research, and simulations. The generalization of connections shows the importance of developing interdisciplinary connections with mathematics and engineering.

The network of connections between the words "physics teaching", and "technologies", revealed the presence of four clusters, which confirmed the importance of digital technologies for teaching physics.

Summarizing the directions of publications by the keywords "physics learning" and "technologies" or "physics education" and "technologies" or "physics teaching" and "technologies" shows that among the presented scientific results, more than half relate to educational and scientific research.

The network of connections according to the words "digital technologies in teaching physics" connected seven clusters that is education, technology, students, physics, digital technologies, science, and teaching. Summarizing the most used keywords they showed that:

- in the period 1995–1999, research on digital technologies in physics was mainly related to www technologies, the Internet, and interactive multimedia;
- in the period 2005–2009, the emphasis shifts to the use of digital technologies in education, problems of secondary education are raised in the context of teaching physics, teaching and learning strategies, research on electronic learning is updated;
- in 2010–2014, works published revealed the problems of teaching physics in higher education, the problems of the effectiveness of existing teaching models were raised, and the emphasis was on knowledge and technologies. In this period, the use of ICT in the teaching of physics and natural sciences begins;
- in 2015–2019, aspects of the use of not only ICT but also social networks and mobile learning are more actively covered, and attention is updated to the motivation of using digital technologies in teaching physics;
- in 2020–2023, the keyword "digital technology" appears for the first time, and the attention of scientists turns to online education and the search for tools to increase the motivation for studying physics, and to develop students' creativity. A retrospective of the emphasis of the publications (we took only those keywords that appeared in the publications more than three times) is presented in Figure 11.

The analysis shows that although publications over the last 5 years has formed a network of only three clusters (education, technology, and digital technology), the focus on learning and teaching technologies, as well as on motivation, remains relevant. Summarizing the search results by the words "physics" and "digital technologies" proved the presence of a significant number of sources devoted to the search for effective technologies in physics, as well as in teaching physics.

The network of connections based on the keywords "physics application" revealed the presence of six clusters that connect models and simulations (application), algorithms and visualization (physics), physical simulations and machine learning (engineering), geometry with applications (applications for physics), design and optimization. The generalization of connections indicates the use of specialized applications in physics education, and at the same time, the importance of modelling, process simulations, and data visualization in physics education. Over the past five years, scientific intelligence has been updated in two directions: physics (algorithms, systems, applications) and machine learning (physical simulations, artificial intelligence, data engineering). This indicates the search for ways to teach physics using machine learning and artificial intelligence.

A more detailed study of the sources for the word "physics-based simulations" demonstrates tendencies towards the simulation of all kinds of physical processes that relate to different sections of physics. The most popular is the plasma and black hole simulation. Along with this, we note the presence of works related to animation, computer modelling, numerical simulations, and data coding. The presence of such keywords in clusters proves the importance of understanding information processes and processing various kinds of data for research in physics. Analysis of the word "physics application" with the clarification of "education" confirmed the popularity of using applications for learning/teaching physics. A search for the word "application to physics" confirmed the importance of mathematical knowledge for teaching physics (about mathematical transformations, differential equations, geometry, and numerical fields).

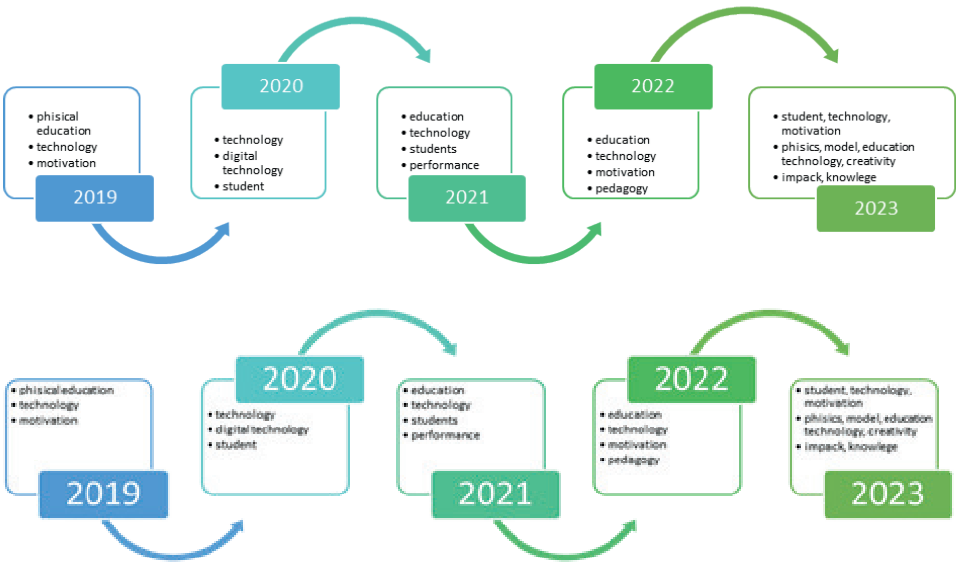


*Figure 11.* The topics of publications that contain words "Augmented reality & physics" in abstracts

S o u r c e: Own work.

The network of connections according to "physics learning mobile" revealed four clusters that link physics learning, achievement, and teaching. The generalization of connections proves the popularity of modern trends in the field of education that is mobile, mixed, and e-learning, as well as means of augmented reality in teaching physics. A search in the abstracts of publications further confirms the use of mobile learning technologies in teaching physics.

The network of connections for the words "virtual reality & physics" revealed clusters such as virtual reality, physics, etc. The generalization of network connections shows the importance of physical modelling, physical simulations, visualization, and mixed reality for the virtualization of physical processes. A search in the abstracts for these words shows that every fifth publication is related to learning/teaching physics. Over the past 5 years, a search for the words “virtual reality and physics” has revealed several clusters, the main one of which connects education, physics, and visualization. At the same time, mixed and augmented reality is updated, which indicates the search for new methods and means of teaching physics.

The network of connections under the words “augmented reality & physics” forms two clusters that connect physical education and design. The directions of research (two out of five) that have the words mentioned in the abstracts touch on the problems of physical education. In the past five years, the augmented reality cluster has seen clear connections with virtual reality, physics learning, game-based learning technologies, and visualization. This indicates the trends of active teaching of physics and the use of mixed reality in the educational process. A search among the abstracts for the words “augmented reality & physics” showed that every second publication is related to learning\teaching.

So, in describing today’s situation of the use of digital technologies in teaching physics, the following important characteristics should be highlighted:

1) General – the use of digital technologies in teaching physics is an actual topic of modern research.
2) Technological – the use of DT in teaching physics takes place in different directions:
    a. the use of digital tools as a means of researching physical processes;
    b. solving physics problems using special programs or mobile applications;
    c. the use of virtual and digital physical laboratories;
    d. the use of virtual, augmented, and mixed reality for teaching physics;
    e. the use of specialized environments for modelling physical processes;
3) educational and motivational:
    a. motivation to study physics and motivation to use digital technologies to study physics;
    b. motivation to deepen mathematical knowledge and skills;
    c. motivation to develop both intellectual skills (computing skills, algorithmic thinking skills, process modelling, etc.), and creative and visual thinking skills;
    d. mastering physics will be successful if interdisciplinary connections between natural sciences, mathematics, engineering, and digital technologies are developed, which separately STEM education.
4) Educational and organizational:
    a. teaching physics today relies on digital technologies and tools that enable simulation, modelling, visualization, and virtualization of physical processes;

b. teaching physics today is connected with the technologies of electronic (including mobile) and mixed, as well as online learning;
c. involves the use of active learning methods, which involve the involvement of DT;
d. physics education today is considered from the angle of machine learning and artificial intelligence as a promising education model.

## Discussion

When describing the situation of the use of digital technologies in teaching physics (hereinafter – the situation), one should take into account the modern development of digital technologies and tools. Since the latter develop quickly and powerfully, they form new directions of development in the field of education. It is DT that determines the trend of this topic in scientific publications of the world. This correlates with the conclusions of review works (Liu & Hwang, 2021; Pando, 2018; Sianes-Bautista et al., 2022).

Another review (Yun, 2020) summarizes the results of 2,959 articles from the American Journal of Physics and 745 articles from Physics Review Physics Education Research. The authors record the growth of interest in the pedagogical content of knowledge in the field of teaching physics, assessment of achievements, and gender of students. They claim that it is pedagogical education and the reasoning process of students that remain the objects of modern research in the field of physics education. At the same time, solving physics problems is a topic in which interest is decreasing. These conclusions correspond to the thesis that the motivation to learn and the ability to realize, understand, and demonstrate are more important today. The ability to solve a problem is increasingly reduced to the ability to use a digital tool.

The technological characteristics of the situation are characterized by various aspects, which are confirmed by review articles of other scientists. Thus, an overview of digital tools as a means of studying physical processes is presented in Camargo et al (2021); Zhang et al., (2023) and others. A generalization of the results of using virtual and digital physical laboratories is presented in Ali et al., (2022). The authors analyse the results of 86 publications and provide recommendations on how to improve their use in teaching physics.

A description of scientific results regarding the use of virtual, augmented, and immersive reality in physics education is provided by Hamilton et al.,(2021), where 29 articles were analysed. The authors claim that they have confirmed a significant advantage of using immersive virtual reality in education. At the same time, the authors emphasize that the correct assessment methods were not always used in the conducted research, and therefore the choice of the correct diagnostic apparatus is important for understanding the potential of immersive augmented reality as a pedagogical method.

The use of specialized environments for modelling physical processes is considered in a review paper (Banda & Nzabahimana, 2021), which presents an analysis of 31 sources that describe the use of PhET simulations in the physics education process. The authors emphasize the conclusion that students' conceptual understanding of physics improves with the use of simulations. Such simulations support the idea of active learning.

The educational and motivational characteristic of the situation is characterized by motivation for various types of educational activities. This is emphasized by Li et al. (2018); McDowell (2019). In particular, the relevance of the problem of motivation to study physics (Alstein et al., 2021) and motivation to use digital technologies in education (Gerhard et al., 2023) are widely researched. It also requires strengthening the motivation to study mathematics (Alipour et al., 2023), the development of intellectual skills (Lv et al., 2022), and visual thinking (Trakosas et al., 2023). The conclusion about the importance of developing interdisciplinary connections correlates with the conclusions of reviews on the implementation of STEM education. Thus, the work of McLure et al. (2022) presents an overview of 35 works related to the organization of STEM projects in various educational institutions. The authors conclude about the diversity of STEM approaches in the literature and note that engineering and natural sciences, including physics, are the most common integrated fields. At the same time, the authors raise the question: to what extent do the projects meet the students' requests, which actualizes the problem of motivation for studying physics?

The educational and organizational characteristic of the situation describes the peculiarities of the organization of physics education. It includes the use of DT for simulation, modelling, visualization, and virtualization of physical processes. In the work of Velasco & Buteler (2017), an analysis of 17 publications was carried out, based on which the importance of using computer simulation in physical education was noted and its possible effects on learning outcomes were noted. Scientists also emphasize the transition to e-learning, which includes mobile and online learning. A review by Cascarosa et al. (2021) examines the concepts of physics education and focuses on the feasibility of building knowledge models that can be implemented in blended learning in higher physics education.

Active learning methods are also important in modern physics education, as confirmed by Odden et al. (2023). Another aspect of teaching physics using machine learning and artificial intelligence is analysed in a review by Dimiduk et al. (2018), which focuses on some positive results and shows that new technologies have the potential to have a transformative impact on approaches to teaching physics.

Analysis of the dynamics of queries in Google Trends shows that among the queries "physics learning," "physics education," and "physics teaching," the most significant interest in the world over the past five years has been observed for “physics education” (an average of 40 points of popularity and out of 100 versus 14 and 17 for the queries “physics learning” and “physics teaching” respectively). The query “physics application” shows an average of 50 points of popularity, and “virtual physics laboratory” – only 2. There are no trends for the query “digital technologies in teaching physics” (not enough data). A similar situation (not enough data) is observed for requests for “digital physics laboratory,” “virtual reality & physics,” and “augmented reality & physics.” Therefore, it can be argued that analytics from Google confirms the popularity of physics applications and education but does not provide detailed information about perspectives on their development.

## Conclusion

The conducted research allows us to draw the following conclusions.

Physics education today is in demand in society. The development of digital technologies and tools supports physics education and its growth. The developers of specialized computer environments and applications provide simplification of calculations, construction of models and the possibility of simulations, etc. At the same time, scientific and pedagogical research traces the problem of young people’s unwillingness to master physics (that fact is based on the appearance of the word “motivation”). Physics for young people is not only tricky but also uninteresting. Therefore, the direction of educational research associated with increasing interest and motivation to study physics based on/ with the usage of digital technology is a trend.

The situation of the use of digital technologies in teaching physics is characterized by four aspects (general, technological, educational-motivational, and educational-organizational). These aspects highlight modern trends in teaching physics. One of the trends is the use of environments where simulation, modelling, visualization, virtualization of physical processes, etc., are possible (the discovered sets of keywords confirm this). Virtual, augmented, and mixed reality are gradually becoming popular. They predetermine the emergence and introduction of new methods of active physics teaching. The popularity of using mobile applications for teaching physics is also increasing. Attempts are being made to use artificial intelligence to teach physics. Another trend in teaching physics is the organization of an educational environment based on mobile or online learning, where active teaching methods are appropriate. Therefore, the leading models of teaching physics become models based on a digital approach and provide interactive teaching methods for their implementation.

The bibliographic analysis by keywords and qualitative analysis of scientific and pedagogical research results in the discussion confirms the importance of developing young people's intellectual skills (computational skills, algorithmic thinking skills, process modeling, etc.) and visual thinking for successful mastery of various physics branches. A demand for integration links between natural sciences, mathematics, engineering, and digital technologies is a trend, further confirmed by the enhanced development of STEM education based on interdisciplinary connections of sciences, technology, engineering, and mathematics. Therefore, the educational process in the future will be saturated with applied tasks, which in their solution, involve using digital technologies and research projects that involve modeling physical processes and predicting possible consequences.

The study additionally actualizes the problem of appropriate training/internship for teachers of natural and mathematical subjects (physics, mathematics, biology, chemistry). The programs of their training today should include mastering various digital technologies and means of teaching physics. The future educational and professional programs should:

- develop intellectual, creative, computational, and visual thinking in future teachers;
- focus on the readiness of physics teachers to develop similar skills among young people;
- form the experience of organizing an electronic educational environment, which provides interactive interaction and high-quality support for teaching physics visually;
- develop the teacher's ability to work with a variety of intelligent systems (virtual laboratories, artificial intelligence, programming environments) to support physics training;
- prepare teachers for the implementation of STEM projects in their professional activities.

The presented research made it possible to describe the situation of the use of computer science in teaching physics and opened up directions for the following scientific investigations in the field of professional training of science teachers: STEM projects in teaching physics, the development of intellectual, creative, computational, visual thinking of students in the process of teaching physics, the effectiveness of using intellectual systems (virtual laboratories, artificial intelligence, programming environments) to support physics education.

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## Wykorzystanie technologii cyfrowych w edukacji: perspektywa nauczania fizyki

S t r e s z c z e n i e

Artykuł ukazuje trendy w wykorzystaniu technologii cyfrowych w nauczaniu fizyki poprzez podsumowanie wyników badań naukowych z ostatnich 20 lat. Aby rozwiązać problem, zastosowano analizę bibliograficzną źródeł naukometrycznej bazy danych WOS z wykorzystaniem narzędzia komputerowego VOSviewer (do budowy i wizualizacji danych bibliograficznych) według stanu na czerwiec 2023 roku. Narzędzie to wykorzystano do analizy publikacji według słów kluczowych (sieć powiązań budowana jest w oparciu o wszystkie słowa kluczowe danych publikacji). W oparciu o zapytania zbudowano sieci powiązań słów kluczowych: „nauka fizyki", „edukacja fizyki", „nauczanie fizyki" i „technologie", a także „technologie cyfrowe w nauczaniu fizyki", „zastosowanie fizyki", „mobilna nauka fizyki", aplikacje fizyczne", „wirtualne laboratorium fizyczne", „cyfrowe laboratorium fizyczne", „wirtualna rzeczywistość i fizyka", „rozszerzona rzeczywistość i fizyka". Wykorzystanie technologii cyfrowych w nauczaniu fizyki charakteryzuje się czterema aspektami (ogólnym, technologicznym, edukacyjno-motywacyjnym i edukacyjno-organizacyjnym). Wyróżniono współczesne trendy w nauczaniu fizyki: wykorzystanie środowisk, w których możliwa jest symulacja, modelowanie, wizualizacja, wirtualizacja procesów fizycznych itp.; rosnąca popularność narzędzi rzeczywistości wirtualnej, rozszerzonej i mieszanej; wykorzystanie aplikacji mobilnych do nauki fizyki; wykorzystanie sztucznej inteligencji w nauczaniu fizyki; organizacja środowiska edukacyjnego opartego na nauce mobilnej lub online, gdzie za odpowiednie uznaje się aktywne metody uczenia się. Potwierdzono znaczenie rozwijania umiejętności intelektualnych młodych ludzi (umiejętności obliczeniowych, umiejętności myślenia algorytmicznego, procesów modelowania itp.) i myślenia wizualnego dla pomyślnego opanowania różnych działów fizyki. Monitorowano zapotrzebowanie na powiązania integracyjne między naukami przyrodniczymi, matematyką, inżynierią i technologiami cyfrowymi w edukacji STEM. Sformułowano zalecenia dotyczące kształcenia nauczycieli fizyki.

S ł o w a  k l u c z o w e: technologie cyfrowe; nauczanie fizyki; nauka fizyki; edukacja fizyczna; nauczyciel fizyki; szkolenie nauczycieli; profesjonalne przygotowanie; technologia cyfrowa w edukacji; wyższa edukacja

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## Aplicación de tecnologías tecnológicas en el ámbito de la tecnología: tierra firme y física

Resumen

El artículo revela las tendencias en el uso de tecnologías digitales en la enseñanza de la física al resumir los resultados científicos de los últimos 20 años. Para solucionar el problema se utilizó un análisis bibliográfico de las fuentes de la base de datos cienciométrica de la WOS con la participación de la herramienta informática VOSviewer (para la construcción y visualización de datos bibliográficos) a partir de junio de 2023. La herramienta se utilizó para analizar publicaciones. por palabras clave (se construye una red de conexiones sobre la base de todas las palabras clave de determinadas publicaciones). Se construyeron redes de conexiones de palabras clave según las consultas: "aprendizaje de física", "educación física", "enseñanza de la física" y "tecnologías", así como "tecnologías digitales en la enseñanza de la física", "aplicaciones de la física", "física móvil". aprendizaje", "laboratorio de física virtual", "laboratorio de física digital", "realidad virtual y física", "realidad aumentada y física". El panorama del uso de las tecnologías digitales en la enseñanza de la física se caracteriza por cuatro vertientes (general, tecnológica, educativo-motivacional y educativo-organizativa). Se destacan las tendencias modernas en la enseñanza de la física: el uso de entornos donde sea posible la simulación, modelado, visualización, virtualización de procesos físicos, etc.; la creciente popularidad de las herramientas de realidad virtual, aumentada y mixta; uso de aplicaciones móviles para aprender física; utilizar inteligencia artificial para enseñar física; organización de un entorno educativo basado en el aprendizaje móvil o en línea, donde se determina que los métodos de aprendizaje activo son apropiados. Se ha confirmado la importancia de desarrollar las habilidades intelectuales de los jóvenes (habilidades computacionales, habilidades de pensamiento algorítmico, procesos de modelado, etc.) y el pensamiento visual para el dominio exitoso de varias secciones de la física. Se ha monitoreado la demanda de vínculos de integración entre ciencias naturales, matemáticas, ingeniería y tecnologías digitales para la educación STEM. Se han formulado recomendaciones para la formación de profesores de física.

Palabras clave: tecnologías digitales; enseñanza de física; aprender física; educación física; profesor de física; formación de docentes; preparación profesional; tecnología digital en educación; educación más alta

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## Использование цифровых технологий в образовании: ландшафт изучения физики

Аннотация

В статье путем обобщения научных результатов за последние 20 лет раскрываются тенденции использования цифровых технологий в преподавании физики. Для решения задачи был использован библиографический анализ источников наукометрической базы данных WOS с привлечением компьютерного инструмента VOSviewer (для построения и визуализации библиографических данных) по состоянию на июнь 2023 года. Инструмент использовался для анализа публикаций по ключевым словам (сеть связей строится на основе всех ключевых слов данных публикаций). Сети связей ключевых слов были построены по запросам: «обучение физике», «физическое образование», «преподавание физики» и «технологии», а также «цифровые технологии в обучении физике», «физические приложения», «лаборатория виртуальной физики», «лаборатория цифровой физики», «виртуальная реальность и физика», «дополненная реальность и физика». Ландшафт использования цифровых технологий в обучении физике характеризуется четырьмя аспектами (общий, технологический, учебно-мотивационный и учебно-организационный). Выделены современные тенденции в преподавании физики: использование сред, в которых возможно моделирование, визуализация, виртуализация физических процессов и т.д.; растущая популярность инструментов виртуальной, дополненной и смешанной реальности; использование мобильных приложений для изучения физики; использование искусственного интеллекта для преподавания физики; организация образовательной среды на основе мобильного или онлайн-обучения, где активные методы обучения признаны целесообразными. Подтверждена важность развития у молодежи интеллектуальных навыков (вычислительных навыков, навыков алгоритмического мышления, процессов моделирования и др.), а также наглядного мышления для успешного освоения различных разделов физики. Выделена потребность в интеграционных связях между естественными науками, математикой, инженерией и цифровыми технологиями для STEM-образования. Сформулированы рекомендации по подготовке учителей физики.

К л ю ч е в ы е  с л о в а: цифровые технологии; преподавание физики; изучение физики; физическое образование; учитель физики; курсы для преподавателей; профессиональная подготовка; цифровые технологии в образовании; высшее образование