STEM TASKS IN PHYSICS TO DEVELOP STUDENTS' DIGITAL COMPETENCE

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Summary

The article explores the potential of STEM-based physics tasks as a means of fostering students' digital competence within the context of contemporary educational transformations. Emphasis is placed on the integration of digital technologies, interdisciplinary approaches, and practice-oriented learning into physics education, aimed at developing skills essential for life in the digital society and Industry 4.0. Based on a review of recent scholarly research, digital competence is defined as encompassing information literacy, skills in using digital devices, data handling, programming, modeling, and presenting research outcomes via digital tools. The study employs a range of theoretical methods, including analysis, synthesis, generalization, systematization, modeling, and predictive reasoning. It generalizes typical examples of STEM tasks in physics implemented through virtual laboratories, simulations, robotics platforms, software-based modeling, and data analytics. A systematized mapping of task types to specific components of digital competence is presented. The study demonstrates that the use of augmented reality (AR), virtual reality (VR), electronic modules, and multimedia platforms (e.g., YouTube) enhances students' learning efficiency and fosters both independent and collaborative activity. The paper also addresses key challenges in implementing STEM tasks, including teacher preparedness, infrastructure modernization, and the adaptation of methodological strategies to blended and distance learning environments. The conclusion argues that the full potential of STEM-based physics tasks can only be realized through integrated educational policies, continuous professional development of teachers, and the creation of pedagogical conditions conducive to implementing interdisciplinary digital projects in schools. Future research should focus on the empirical evaluation of the effectiveness of such STEM tasks in real-world educational settings.

Key words: STEM education, digital competence, physics teaching, project-based learning, virtual laboratories, robotics, digital tools, interdisciplinary approach, teacher.

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1. Introduction

In contemporary educational practice, the integration of the STEM approach (Science, Technology, Engineering, Mathematics) into the teaching of natural sciences, particularly physics, is gaining increasing relevance. This approach implies not only the interdisciplinary nature of the educational process but also the active use of digital technologies, which creates prerequisites for the development of students' digital competence *(Semenikhina et al., 2022b; Yurchenko et al., 2023a)*. Engaging students in STEM-based physics tasks that integrate elements of programming, digital modeling, data analysis, and the use of electronic educational platforms contributes to the formation of both subject-specific and cross-cutting competencies, such as critical and creative thinking. In the context of labor market transformation and the global implementation of Industry 4.0 technologies, digital skills are considered one of the key components of students' general educational preparedness. Educational research confirms that the use of digital tools in the process of solving problem-based tasks positively correlates with improved academic performance and increased levels of students' cognitive engagement. Thus, the design and implementation of digitally oriented STEM tasks in physics emerge as an effective means of developing students' digital competence within the framework of the competency-based approach to learning.

2. Review of literature

In contemporary educational scholarship, increasing attention is being paid to the problem of developing students' digital competence within the context of STEM education. Researchers emphasize that the digital learning environment provides optimal conditions for students' self-expression, the development of their creative potential, and the enhancement of creative thinking through hands-on activities that incorporate innovative digital tools *(Wang & Li, 2022)*. Digital literacy plays a crucial role in this process, encompassing both technical skills and the ability to effectively engage with digital resources in blended learning contexts *(Le et al., 2022; Rudenko et al., 2025)*.

An examination of the integration of digital components in STEM-related instruction shows that even at the early stages of education, subject-oriented digital platforms are widely used, increasing student engagement and supporting the development of digital competence. One of the most effective pedagogical strategies in this regard is Project-Based Learning (PBL), which immerses students in real-world problem solving using digital technologies. Research has shown that PBL not only fosters critical and creative thinking but also improves students' collaboration skills *(Khoiri et al., 2023)*.

Considerable attention has also been given to STEM-oriented project-based learning (STEM PjBL), which has a positive impact on students' self-efficacy when solving physics problems. Empirical data indicate that this form of learning enhances student motivation, fosters awareness of the connection between academic content and real-life situations, and supports career identity development *(Samsudin et al., 2020; Semenikhina et al., 2022a)*.

The analysis of existing research highlights the key components of students' digital competence that can be developed through STEM-based physics tasks: information literacy (i.e., the ability to search, analyze, and evaluate digital sources); practical skills in using digital devices (e.g., sensors, mobile labs, simulators) for conducting experiments; and digital communication, which involves presenting research findings using digital tools. Thus, the body of research reviewed supports the potential of STEM tasks as an integrated means of fostering digital skills in the context of physics education. Based on this, the **aim of the article** is defined as the substantiation of the possibilities for developing students' digital competence through the implementation of STEM tasks in physics instruction.

3. Methodology

This study employed a set of theoretical methods that provided a comprehensive understanding of the research problem and facilitated the development of well-substantiated conclusions: a*nalysis of scientific literature* was conducted to identify current approaches to the integration of STEM education in physics instruction and to examine the factors influencing the development of students' digital competence; s*ynthesis and generalization* were used to determine the essential characteristics of STEM tasks, their typology, and their educational potential; *systematization of empirical data* presented in scientific sources made it possible to establish correlations between the types of tasks, digital tools, and the corresponding components of digital competence; m*odeling* was applied to construct a generalized structure of STEM-based physics tasks aimed at fostering digital competence, taking into account interdisciplinary principles; p*redictive generalization* was employed to outline future perspectives and the necessary conditions for the integration of digital technologies into physics education in order to develop students' competencies within the digital environment.

4. Results

The implementation of the STEM approach in physics education contributes not only to a deeper understanding of natural laws but also to the development of students' digital competence. One of the key areas of this implementation is the integration of robotics and programming into the educational process. Working with microcontrollers, sensors, and algorithms enables students to combine theoretical knowledge with practical activities, which, according to empirical research, significantly enhances motivation and interest in physics *(Mazur & Franko, 2023)*.

Practice-oriented learning involves students in real-life projects where they apply physical laws to create robotic systems and controlled mechanisms. The use of platforms such as Arduino or LEGO Mindstorms allows for the modeling of mechanical, electrical, and electromagnetic phenomena in real time. Additionally, programming physical models creates opportunities for experimentation that were previously impossible or technically challenging in traditional school laboratories.

Students' digital competence is developed through mastering basic algorithmic thinking, logic, and control of technical systems, as well as through practical engagement with modern electronics, sensors, motors, and microcontrollers *(Bondarenko, 2018; Shamonia et al., 2019)*. Simultaneously, STEM-based physics tasks support an interdisciplinary approach by integrating knowledge from computer science, mathematics, electronics, and engineering. This fosters a comprehensive understanding of content and promotes systems thinking *(Ilnitska, 2020)*.

Such tasks stimulate research, critical, and creative thinking. They teach students to work in teams, solve complex problems, analyze experimental results, and present their findings, skills that align closely with key components of digital competence *(Kramar & Shyshkina, 2024)*.

This study has generalized effective types of STEM-based physics tasks aimed at developing digital competence:

− *Modeling physical phenomena in software environments* (e.g., Scratch, Python) allows students to visualize laws of mechanics, simulate motion, and analyze real-time parameter changes.

− *Virtual laboratories* (e.g., PhET, Algodoo) support conducting experiments in digital environments with adjustable parameters and observable outcomes.

− *Robotics projects* (e.g., Arduino, LEGO Mindstorms) focus on designing and programming physical models using sensors, which fosters engineering thinking.

− *Big data analysis* (e.g., Excel, Google Sheets) trains students in data processing, visualization, building graphs, and drawing conclusions.

− *Digital presentations and video tours* develop information literacy, the ability to communicate research results, and disseminate them in digital formats.

The use of modern digital platforms significantly expands the didactic potential of STEM-based tasks. Technologies such as augmented reality (AR) and virtual reality (VR) provide high levels of student immersion, contributing to deeper knowledge acquisition and skills development through interactive engagement *(Setiawan et al., 2023)*. The use of electronic modules based on iSTEM or Ethno-STEM approaches helps adapt educational content to the learners' needs and contexts while supporting independent learning *(Purwanto et al., 2021; Sari et al., 2023)*.

Project-based learning supported by platforms like YouTube enables students to create their own educational content, enhancing digital creativity and reinforcing their understanding of physics concepts *(Widiastuti et al., 2021)*.

To provide a practical justification for the potential of STEM-based tasks in developing students' digital competence, the study has summarized common task types already used in educational practice or recommended by scholarly sources (Table 1). Each task type is characterized not only by its didactic potential but also by its targeted contribution to specific components of digital competence, such as programming, working with digital sensors, data visualization, and multimedia communication.

Table 1

Examples of STEM-based Physics Tasks and the Development of Digital Competence

Type of Task	Task Description	Digital Tools	Digital Competence Components
Modeling physical phenomena	Creating simulations of the motion and interaction of bodies	Scratch, Python (matplotlib, Pygame)	Programming, visualization, and analytical thinking
Virtual laboratories	Conducting experiments in simulation environments	PhET, Algodoo	Interactive engagement, data analysis, and interpretation
Robotics projects	Designing and programming devices	Arduino, LEGO Mindstorms	Hardware interaction, algorithm design, and engineering thinking
Data analysis	Graphing and analyzing experimental data	Excel, Google Sheets	Data processing, digital literacy
Digital presentations/ videos	Visualizing and explaining physical phenomena	PowerPoint, Canva, YouTube	Multimedia communication, content creation

The analyzed examples demonstrate the high potential of STEM-based physics tasks as an effective means of integrated digital competence development. Their implementation in the learning process engages students in practical, interdisciplinary activities that foster digital creativity and 21st-century skills. It is important to emphasize that the effectiveness of such tasks depends largely on the deliberate selection of digital tools, pedagogical support, and the creation of conditions for reflective analysis of learning activities.

5. Discussion

The findings confirm that STEM-based physics tasks integrating digital tools, interdisciplinary approaches, and practical orientation serve as an effective means for fostering students' digital competence. Such activities not only enhance the assimilation of educational content but also contribute to the development of essential skills for successful socialization in the context of a digital society and Industry 4.0. The combination of physics knowledge with digital technologies facilitates the formation of information literacy, engineering thinking, analytical abilities, and presentation skills, which align with the framework of 21st-century competencies.

Despite their significant didactic potential, the implementation of STEM tasks in physics education entails a series of challenges. One of the critical factors determining the success of such tasks is the professional readiness of teachers. To effectively deliver STEM education, teachers must possess not only deep subject-specific knowledge but also competencies in the integration of technology, engineering approaches, and mathematical modeling into physics curricula *(Jiménez-Fanjul et al., 2022; Sulaeman et al., 2022)*. Notably, the importance of continuous professional development is emphasized as it ensures consistency in instruction, ongoing enhancement of digital skills, and teacher motivation to adopt innovative practices.

Other challenges include pedagogical and organizational difficulties associated with the implementation of project-based learning within the constraints of limited instructional time, as well as the adaptation of such practices to blended or online learning formats *(Jiménez-Fanjul et al., 2022; Yurchenko et al., 2023b)*. In the context of early STEM education, which also encompasses elements of digital literacy, researchers highlight the shifting role of the teacher from knowledge transmitter to facilitator of learning, who stimulates students' cognitive engagement and creates conditions for inquiry-based learning *(Kalogiannakis et al., 2023; Leung, 2023)*.

Special attention should also be paid to the role of out-of-school environments in developing digital literacy. Research shows that children's experiences with digital technologies at home, as well as the sociocultural context of these interactions, play a significant role in preparing them to engage with STEM content in formal education settings *(Neumann et al., 2023; Soyoof et al., 2024)*. In this context, STEM tasks may serve as a tool not only for formal but also for informal learning, necessitating new models of collaboration among schools, families, and digital environments.

Thus, the results of this study demonstrate the high potential of STEM-based physics tasks as a tool for developing students' digital competence. At the same time, the full realization of this potential requires systemic support from education policy, enhancement of teacher training programs, and adaptation of task content to the contextual diversity of learning environments.

6. Conclusions

This study has substantiated the potential of STEM-based physics tasks as an effective means for fostering students' digital competence. Based on the analysis of current scientific literature and the synthesis of task examples, it has been demonstrated that the integration of digital tools into the teaching of physics contributes to the development of information literacy, programming skills, data visualization, data analysis abilities, as well as critical and creative thinking. The success of such educational practices is ensured by the combination of interdisciplinary approaches, project-based learning, and the use of AR/VR technologies, digital platforms, and simulations.

Nevertheless, the implementation of these approaches requires addressing several systemic challenges. Key among them are teacher readiness for STEM integration, availability of appropriate technical infrastructure, support for continuous professional development, and adaptation of educational content to the sociocultural and developmental context of learners. Particular emphasis should be placed on developing digital literacy from an early age, which lays the groundwork for effective engagement with STEM-oriented tasks in future learning.

Looking ahead, the implementation of STEM tasks in physics education should be based on the integration of digital tools into a structured pedagogical model that combines project-based activities, inquiry-based learning, collaboration, and independent student work. Investment in infrastructure development, the creation of didactic materials and digital content, and support for teachers in acquiring digital pedagogical skills are essential conditions for the ongoing transformation of physics education in the digital age.

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