Physics Education in EU High Schools: Knowledge, Curriculum, and Student Understanding

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Abstract
This study examines the status of physics education in EU high schools, focusing on student understanding, curriculum organization, and knowledge transmission. The research aims to uncover potential gaps or opportunities for improvement in physics education in the European Union by looking at five important characteristics. Enhancing the overall educational experience and preparing students for future academic and professional pursuits requires an understanding of the quality of knowledge imparted to students, the efficacy of the curriculum in reaching educational goals, and the level of student comprehension. By offering insightful information, this study can guide instructional practices and policy in secondary schools across the European Union, potentially leading to significant improvements in physics education. A more thorough investigation of pedagogical strategies and their effects on student learning outcomes may benefit future studies in this field. Furthermore, examining any variations in physics education among the different EU member states may provide insightful comparative analysis.

Keywords: Physics Education, EU, Knowledge, Curriculum, Student Understanding.


Introduction
Physics education is pivotal in fostering students' scientific literacy, a key component in preparing them for careers in STEM sectors. High schools in the European Union are instrumental in this process, as they are responsible for developing curricula, imparting knowledge, and promoting physics comprehension among students. The study of physics allows students to delve into the universe's fundamental laws and sharpen their critical thinking skills, laying a solid foundation for further exploration at the university level (Sadler & Tai, 2001). Students expand their intellectual horizons and hone their problem-solving abilities by grappling with complex concepts such as relativity and quantum mechanics. Physics instruction in EU high schools equips students with the analytical skills necessary to tackle real-world problems and foster innovation (Tiberghien et al., 2001). Therefore, emphasizing physics instruction in EU high schools is crucial in nurturing well-rounded, scientifically literate individuals who can significantly contribute to society.
As seen in the VM3.0 project financed by the European Union, integrating digital microscopy and virtual microscopy apps demonstrates the growing trend toward new teaching approaches in higher education institutions across Europe (Amalinei et al., 2024). The adoption of STEAM educational concepts in universities across the European Union indicates the necessity for pedagogical approaches to be flexible and modern, as highlighted by the movement in medical education towards digital transformation (Litvin & Stratila, 2023). The quality and applicability of physics instruction in EU high schools can be improved by examining best practices for implementing STEAM competencies in EU institutions (Herro et al., 2018).

The importance of physics instruction in EU high schools cannot be overstated. The fundamental science of physics forms the basis of many contemporary innovations and technology. Students who study physics education have a thorough awareness of the physical world and analytical, critical thinking, and problem-solving abilities that are highly sought after in today’s workforce (Hazari et al., 2010). A strong emphasis on physics education in high school can help close the knowledge gap between theory and practice in the EU and prepare students for employment in various STEM sectors. Furthermore, a significant focus on physics education can help the EU’s scientific research and innovation sector. Thus, funding physics education in EU high schools is essential for developing a trained labor force and promoting scientific advancement.

Knowledge in Physics Education

High school physics instruction is changing due to new pedagogical paradigms and technological breakthroughs (Oliveira et al., 2019). This fact underscores the importance of incorporating character development and values into education, which aligns with the overarching objective of producing well-rounded people. Furthermore, as shown, the usefulness of cell phones as measuring instruments in physics labs emphasizes the potential of technology to improve students' science process abilities (Evains et al., 2024). The incorporation of novel instruments not only amplifies student involvement but also denotes a progression towards technologically integrated learning settings, signifying the necessity for ongoing investigation into the function of technology in physics education. As physics education develops, students at EU high schools can develop a deeper grasp and appreciation of the topic by adopting varied approaches and embracing technological advancements.

In order to promote student comprehension and knowledge acquisition, a substantial emphasis on theoretical underpinnings is necessary for effective physics education in high schools. By using the concepts of modeling instruction, as proposed by Li (2015), educators have the potential to improve students' intrinsic motivation and foster their conceptual knowledge of physics. Additionally, as (Friedman, 2005) emphasizes the significance of evidence-based arguments in developing the area of physics education, referencing and citation practices play an important part in design research. To encourage deeper student involvement and the development of critical thinking abilities, curriculum development and instructional practices in physics education can be guided by incorporating theoretical frameworks, such as those suggested in design research. Promoting a thorough knowledge of physics ideas in EU high schools requires a holistic approach combining theoretical underpinnings with evidence-based activities.

The way that physics education is shaped by the opinions of both teachers and students has a significant impact on both academic achievement and the adoption of new
A study conducted in Bhutan to investigate student perceptions found that improved academic achievement at the middle and high secondary levels was related to favorable attitudes about learning geography (Pokhrel & Chhetri, 2024). Similarly, a Surabaya case study revealed differing opinions among physics instructors about introducing a new curriculum, highlighting the necessity of ongoing assistance and training to promote adjustment and enhance teaching methods (Puteri et al., 2024). These revelations highlight how instructor and student viewpoints interact intricately to shape effective physics instruction. By recognizing and addressing these attitudes, educational stakeholders can create a more favorable learning environment that fosters student knowledge and engagement in physics at the high school level inside the EU.

Today, technology integration in physics education has grown significantly (Banda & Nzabahimana, 2021). Technology presents particular chances to improve student comprehension of challenging physical ideas, learning, and engagement. A dynamic learning environment that accommodates a range of learning styles and abilities can be created by instructors by combining simulations, visualization tools, internet resources, and interactive activities (Hasas et al., 2024). Studies have indicated that incorporating technology into physics education can improve student learning outcomes and knowledge retention (Banda & Nzabahimana, 2023). Technology also allows students to have individualized learning experiences where they can study subjects quickly and get feedback on their work. Educators must carefully choose and incorporate technology tools to ensure that learning objectives are met and relevant learning experiences are fostered (Altınay, 2020). Physics instruction in secondary schools can be improved to better prepare students for success in the classroom and the workplace by utilizing technology.

It is important to evaluate students' comprehension and proficiency in physics in high school through various assessment techniques. Multiple-choice questions, written assignments, laboratory reports, and oral exams are frequently utilized to assess students' comprehension and analytical abilities. A comprehensive assessment strategy should guarantee a thorough assessment of physics knowledge acquisition (Marcinauskas et al., 2024). Educators can more accurately assess students' ability to apply abstract ideas to practical situations by integrating hands-on experiments, problem-solving activities, and critical thinking exercises. Furthermore, integrating formative evaluations into the semester can offer instructors and students insightful feedback, promoting a more efficient learning process and permitting prompt intervention when needed (McLoughlin & Van Kampen, 2019). Ultimately, encouraging deep learning and a deeper comprehension of physics concepts among students in EU high schools requires a well-rounded assessment technique.

Curriculum Development in Physics Education

The focus group discussion (Einarsson et al., 2023) revealed that university teachers are working together to create new curricula, emphasizing the significance of cooperation procedures in curriculum development. This study sheds light on the importance of collaborating pedagogically across departments and faculties, offering insights that may motivate teachers to take on similar curriculum development projects in physics education. Simultaneously, an analysis of scholarly research on curriculum development in undergraduate teacher training programs (Erdamar, 2023) indicates an increasing inclination toward improving curriculum design in secondary education. The results highlight the necessity of a unified, international community of practice to
improve curriculum frameworks and instruction, especially in teaching physics. A holistic approach to improving physics education curricula in EU high schools can be fostered, promoting innovation and student understanding, combining insights from collaborative teaching experiences and academic research on curriculum creation (Braun & Huwer, 2023).

In order to match national and EU requirements in physics education, research on the coherence of curriculum content at various educational levels is important (Shuey et al., 2019). By examining the concepts of curriculum continuity from elementary school to tertiary education, teachers can improve the coherence and efficacy of physics instruction (Tsouri et al., 2024). According to Nurmukhamedova et al. (2024), system analysis offers a methodological framework for analyzing the content transfer between elementary and high school physics courses. Including experimental investigation in the curricular standards reflects efforts to raise the caliber of physics instruction. Nevertheless, obstacles like time constraints in the classroom can prevent these advancements from being fully realized. Finally, harmonizing national and EU criteria can be achieved by addressing these obstacles, improving instructional tactics, and promoting a more comprehensive physics education program in high schools.

To improve student learning results and engagement in science education, pedagogical approaches must be used when teaching physics (Bidarra & Rusman, 2016). Studies have indicated that utilizing cutting-edge resources like virtual physics laboratories can greatly impact students' performance and cognitive achievements in subjects like motion (Yawo, 2020). This emphasizes incorporating technology into physics instruction to promote a deeper comprehension of scientific ideas. For example, writing across the curriculum programs can improve students' writing and critical thinking abilities, which are important for scientific inquiry and debate. Understanding writing as a tool for learning and communication is essential in bridging the gap between high school and university-level academic writing demands, even though there may be obstacles in developing sustainable writing structures across the high school curriculum (Herkner et al., 2012). Thus, a comprehensive strategy incorporating technology, writing assistance, and pedagogical techniques can enhance physics instruction and enable students to succeed academically.

The way physics is taught in EU high schools is changing, emphasizing the importance of interdisciplinary ties in the curriculum. ETH Zurich, the Swiss Federal Institute of Technology, has demonstrated a proactive approach to incorporating sustainability into its architecture curricula, as Kastner and Langenberg (2023) highlighted. This approach highlights the necessity for new disciplinary and interdisciplinary approaches towards a sustainable built environment. The idea that encouraging multidisciplinary viewpoints might enhance educational opportunities and better equip students for issues they would face in the real world is bolstered by this case. As noted by (G. Van Oost et al., 2020), the Erasmus Mundus Joint Master’s Degree program FUSION-EP similarly highlights the importance of incorporating research-oriented education within an international collaboration to address the urgent problem of global energy supply in the field of magnetic fusion. Offering specific courses in fusion engineering and science, this program demonstrates how interdisciplinary collaboration may improve students' competencies and prepare them for research led by industry. Incorporating interdisciplinary links into the physics curriculum broadens students' horizons and gives them the tools to address challenging global issues.

Promoting fair access to STEM fields and creating inclusive learning environments are two reasons why addressing diversity in physics education is important. As explained
threshold ideas offer a framework for identifying and addressing difficult physics curriculum areas that students might find difficult. Educators can improve student understanding and encourage deeper integration of knowledge by identifying and emphasizing these liminal notions. Furthermore, studies on the career options made by rural students, as noted by Vaziri et al. (2020), provide insight into the distinct socio-cultural experiences that shape people's choices to major in engineering. Strategies to increase the number of diverse student populations participating in physics education can be informed by understanding the unique obstacles that rural areas confront in promoting and encouraging engineering as a career choice. Teachers can improve their pedagogical strategies to guarantee that all students can access a more inclusive and accessible physics curriculum by utilizing the insights gained from these studies.

Student Understanding in Physics Education

China's high engineering education changed dramatically during the War of Resistance, emphasizing the development of specific skills necessary for the war effort and pragmatism (Chen, 2024). During this time, it was stressed how important it was to modify the curriculum and teaching strategies to meet the demands of the war effort. For example, national defense-related studies were added, and the emphasis on improving practical abilities in engineering disciplines was increased. Furthermore, during this time, parents encouraged their children to major in engineering, and students took satisfaction in pursuing such a major. This changed the social climate to one that valued practical courses like engineering. The development of engineering education during this turbulent period strengthened the engineering disciplines' capacity to support national development. It highlighted higher education's vital role in meeting the nation's real-world demands. This historical background highlights the critical role that engineering education plays in times of crisis and illuminates the dynamic interaction between education and national objectives.

Research conducted in Greece reveals that students at the university level, even in the Physics Department, have severe misconceptions about basic concepts in classical mechanics (Stylos et al., 2008). In addition, university students have misconceptions about the modern applications of electromagnetic radiation, such as mobile phones, wireless networks (Gavrilas et al., 2022), and radioactivity (Migdanalevros & Kotsis, 2021). These findings shed light on misconceptions and conceptual understanding in physics education (Kotsis, 2023). According to the study (Samara & Kotsis, 2023), students still have false notions about magnetism even after being exposed to organized courses. Even in the face of educational improvements, these myths endure. The results highlight the significance of tackling and correcting these enduring misunderstandings using focused teaching approaches that encourage a more profound and precise understanding of physics concepts among pupils in upper education environments in the European Union.

Integrating real-world linkages and practical applications into physics instruction is important for improving student comprehension and engagement. According to (Valko and Osadchy, 2021), project technology effectively teaches natural sciences by encouraging students' self-organization, teamwork, and hands-on experiences. Project-based learning can promote a more thorough comprehension of physics principles and strengthen links with theoretical topics by emphasizing action-oriented assignments and situational relevance (Goldstein & Bevins, 2016). Moreover, the Maker movement
emphasizes the value of creativity, a do-it-yourself mentality, and community cooperation in education, as covered in Lin et al., 2021. Incorporating these components into physics education can enhance the educational process and motivate learners to investigate the real-world applications of physics. EU high schools can establish a dynamic and immersive learning environment that fosters students' problem-solving abilities and innovation mindset, ultimately equipping them for success in the always-changing field of physics by integrating project-based activities and maker-oriented projects into the curriculum.

Teachers can use some ways to increase students' interest and involvement in physics. Including practical experiments and demonstrations in the curriculum is one efficient way for students to apply their theoretical knowledge in a real-world environment. This stimulates their curiosity and interest in the subject matter and reiterates their comprehension of the important ideas. Furthermore, facilitating group projects or conversations that promote collaborative learning can help students connect with the subject matter more deeply and build critical collaboration skills. Moreover, providing practical examples and applications of physics concepts can highlight the subject's applicability to daily life and inspire students to take an active role in their education. By integrating these techniques, teachers can establish an engaging and dynamic classroom that ignites students' interest in physics and increases student involvement.

Conclusion

When considering the different aspects of physics education in EU high schools, combining cutting-edge cognitive neuroscience-based instructional frameworks with more conventional academic subjects like math and physics offers a strong strategy for improving student engagement and learning outcomes. As demonstrated by (Akasheh et al., 2018), the Knowledge and Curriculum Integration Ecosystem framework represents a promising move toward active learning approaches that address students' underlying inadequacies and encourage systematic knowledge acquisition. This innovative method goes beyond specific courses to promote related ideas, promoting a whole curriculum structure meant to improve student comprehension and involvement. Although there is ongoing discussion regarding accepting non-traditional subjects like architecture at the A-level for high school admissions, S. Unwin's (2010) critical perspective highlights the significance of expanding students' academic horizons with traditional subjects to guarantee a well-rounded education. These observations highlight the importance of comprehensive educational approaches in fostering the next generation of physicists and intellectuals in the EU high school environment by integrating multiple perspectives and methodologies.

From different EU schools (Tsiouri et al., 2024), some important conclusions about the teaching of physics emerged. First, it was discovered that students at various institutions have significantly diverse physics knowledge and comprehension levels. This emphasizes the necessity of a standardized curriculum to guarantee that every student has the same baseline knowledge. The study also found a link between student performance and teaching quality, highlighting the need for qualified, experienced physics teachers. Additionally, the study found that students strongly preferred interactive and hands-on learning experiences, supporting that hands-on learning might improve students' comprehension of challenging physics ideas. Our results highlight the significance of ongoing assessment and enhancement of physics
instruction in EU high schools to guarantee that pupils are well-equipped for subsequent pursuits in the discipline (McLoughlin & Van Kampen, 2019).

Given the scholarly literature on the endeavors of educational establishments to generate employable graduates, it is important to contemplate the consequences of physics instruction practices and policies in European Union high schools. The literature has shown (Lattuca & Stark, 2009) that curriculum design, instructional strategies, and opportunities for industry collaboration shape graduates' competitiveness and caliber. Thus, it is important to include techniques that improve communication, critical thinking, and problem-solving abilities, as well as to create a learning environment that supports the development of skills relevant to the demands of the labor market. Furthermore, integrating physics education with 21st-century competencies like inventiveness, originality, and proficient communication might improve students' preparedness for the changing nature of the job market. By integrating these findings into educational policies and practices, European Union high schools may guarantee that their physics curriculum provides students with the essential skills to thrive in a worldwide market.

To improve knowledge, curriculum development, and student understanding, it will be important for future research in the field of physics education in EU high schools to concentrate on several important topics. Future studies in this field could benefit from a more in-depth examination of certain pedagogical approaches and their effects on student learning outcomes, as well as cross-EU comparative studies (Chitez et al., 2018). First and foremost, studies should investigate how well cutting-edge teaching techniques like flipped classrooms and active learning tactics work to increase student engagement and understanding of challenging physics material. Second, to give students a more practical and relevant understanding of physics, it is important to investigate the effects of integrating interdisciplinary links and real-world applications into the physics curriculum. Further research should examine how technology—like virtual labs and simulations—affects students' learning results in physics classes. Teachers and legislators can make well-informed decisions to improve the standard of physics instruction in EU high schools by addressing these research gaps.

Considering the current situation of physics instruction in EU high schools, opportunities and challenges still lie ahead. Although curriculum design and teaching approaches have advanced, there is always potential for improvement in helping students gain a deeper knowledge of physics. Concluding remarks on this intricate subject matter ought to underscore the necessity of sustained cooperation among instructors, legislators, and scholars to improve the caliber of physics instruction. Educators can better prepare students for success in the rapidly changing scientific environment by promoting interdisciplinary approaches and incorporating real-world applications into the curriculum. We must continue to strive to inspire the next generation of scientists and inventors and foster a love of physics.

**Conflict of interests**

No conflict of interest.
References


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