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Physics education in the training of engineers for digitized industry

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Abstract. - This paper addresses the synergy between engineering and physics education, highlighting how applying physics principles and concepts in engineering projects can significantly enrich STEM education. Innovative pedagogical approaches that foster a deeper understanding of physics by solving practical problems and integrating theory with practice are discussed, thus promoting more effective and meaningful learning in engineering. The main results show that, despite the inclusion of new technological strategies in the engineering career, it is not advisable to eliminate the teaching of physics in the engineering education curriculum and that, on the contrary, it is essential to reinforce these theories.

Keywords: STEM, engineering education, physical theories, physics education.

La enseñanza de la física en la formación de ingenieros para la industria digitalizada

Resumen: Este estudio se enfoca en el análisis de la responsabilidad social universitaria en la formación de ingenieros. Para ello se analizaron estudiantes de ingeniería y se contrastó con estudiantes de ciencias sociales, esto con la finalidad de relacionar la educación técnica con la educación social. La investigación tuvo un enfoque cuantitativo y descriptivo, utilizando un diseño no experimental de corte transversal. La muestra comprendió a 1023 estudiantes de ingeniería y ciencias sociales seleccionados de manera intencional. Se aplicó una escala validada específica para evaluar la percepción de los estudiantes en relación con su responsabilidad social en el contexto universitario y en la vida común. Los resultados indicaron un nivel medio de responsabilidad social con una tendencia a ser bajo en el grupo de estudiantes universitarios analizados. Además, se observó que las carreras de ingeniería deben reforzar el compromiso social de los estudiantes.

Palabras clave: STEM, educación en ingeniería, teorías físicas, enseñanza de la física.

I. INTRODUCTION

Physics, a fundamental element of science, has proven to be a crucial pillar in understanding and developing modern technology. As we move into the twenty-first century, the role of physics in engineering and technology has become even more prominent, driving significant advances in fields as diverse as renewable energy, quantum communication, and space exploration. According to data from the World Health Organization (WHO), in 2021, more than half of the world's population had access to the Internet. This achievement would not have been possible without the underlying physical foundations of data transmission over global fiber optic networks [1].

However, despite these advances, physics education faces persistent challenges worldwide. According to UNESCO's Global Education Monitoring Report [2], published in 2020, the lack of equitable access to quality education in science, including physics, remains a global concern [3]. The gap in science education is particularly pronounced in low-income countries, raising crucial questions about how to improve the pedagogy and accessibility of physics globally.

In this context, this paper examines the intersection between engineering and physics education, highlighting how the practical application of physical principles in engineering projects drives technological innovation and can significantly enrich the way physics is taught and learned. Through examples and innovative pedagogical approaches, we explore how integrating theory with practice in physics teaching can foster a deeper understanding of the discipline and inspire the next generation of engineers and scientists to tackle the most pressing global challenges. In this sense, the collaboration between engineering and physics education is an essential bridge to a technologically advanced future and a more informed and capable society.

In several Latin American countries, a worrying phenomenon has been observed in higher education, where attempts are made to eliminate physics from engineering careers. This trend, often motivated by the need to simplify curricula and accelerate the training of professionals in the STEM (Science, Technology, Engineering, and Mathematics) field, poses significant challenges for the quality and breadth of training of future engineers. One of the main risks lies in losing a solid foundation in physics, which is essential for understanding and applying the fundamental principles underpinning modern engineering and technology [4][5].

Removing physics from engineering careers can also negatively impact graduates' ability to solve complex problems and face multidisciplinary challenges in the real world. Physics provides the theoretical and conceptual tools needed to address a wide variety of problems in engineering, from the design of power systems to the development of advanced medical devices [6]. The omission of physics could result in incomplete training, limiting the versatility and adaptability of future engineers in the face of a constantly evolving job landscape.

In addition, the elimination of physics in engineering careers could undermine the ability of these countries to stay at the forefront of technological innovation and scientific research. Physics is the basis of numerous technical and scientific advances, and depriving students of this discipline could reduce their ability to contribute to global scientific and technological progress. Ultimately, education policymakers in Latin America must consider the long-term impacts of this trend and seek a balance between simplifying curricula and maintaining comprehensive engineering and STEM training.

II. STEM methodologies and the challenges in engineering training

STEM methodologies (Science, Technology, Engineering, and Mathematics) are pedagogical approaches that promote the interdisciplinary integration of these four disciplines in education [4][7]. These methodologies aim to foster critical thinking, problem-solving, and creativity in students, preparing them to tackle complex challenges in the real world. Here are some of the most relevant STEM methodologies:

Project-Based Learning (PBL): This methodology engages students in hands-on projects related to real-world problems. Students apply STEM concepts to solve concrete challenges, encouraging practical application of knowledge and teamwork [8].

Collaborative Learning: In STEM learning, collaboration between students is promoted. Working in teams allows students to share ideas, face challenges, and develop communication skills, all essential in engineering training.

Use of Technology: Modern technologies, such as simulations, modeling software, and specialized hardware, play a critical role in STEM teaching. These tools help students understand abstract concepts and gain practical skills.

Focus on Problem Solving: STEM methodologies focus on developing skills to identify and solve complex problems. Students learn to deal with ambiguous situations and to apply the scientific method to arrive at informed solutions.

Active Learning: Instead of traditional passive teaching, STEM learning actively engages students. They participate in experiments, discussions, and hands-on activities that foster more profound, meaningful learning.

However, the effective implementation of STEM methodologies in engineering training faces several challenges:

Resources and Equipment: STEM teaching often requires expensive equipment and advanced technology. Not all schools have access to these resources, which creates inequalities in STEM education.

A. Teacher training

Educators must be trained to implement STEM methodologies effectively. Continuous teacher training is essential to keep up with trends and best practices [6] [9]. Training educators in effectively implementing STEM methodologies is critical to ensuring students get a quality education in these disciplines. For this, teachers must develop and strengthen the following activities:

Updated Knowledge: Continuous training allows educators to keep up with advances in Science, Technology, Engineering, and Mathematics. Since these fields constantly evolve, teachers must know about the latest research, technologies, and pedagogical approaches. This allows them to offer students up-to-date and relevant information.

Specific Teaching Skills: STEM methodologies often require particular teaching approaches, such as project-based learning, problem-solving, and hands-on teaching. Educators must acquire and hone these skills to effectively guide students through enriching STEM learning experiences.

Adaptability: Continuous training helps teachers adapt to changing student needs and preferences. Teaching methods that worked in the past may not be the most effective today. The training allows them to adjust their pedagogical approaches to better address the changing challenges and demands of the classroom.

Curricular Integration: STEM teaching often involves the integration of multiple disciplines into the curriculum. Educators must connect science, technology, engineering, and math concepts coherently and meaningfully. This may require interdisciplinary collaboration and a solid understanding of how these disciplines relate.

Technology Tools: In the digital age, educators should also be familiar with the technological tools and resources available to improve STEM teaching. This includes simulation software, virtual labs, online learning platforms, and other educational technologies that can enrich the learning experience.

Practical Assessment: Ongoing training also addresses assessing students in STEM contexts. Teachers must learn to effectively determine understanding, practical skills, and problem-solving using methods beyond traditional tests. This involves creating authentic assessments and interpreting the results to improve teaching.

B.Encourage Diversity

Engineering training should be inclusive and diverse [2]. Overcoming gender biases and promoting the participation of underrepresented groups in STEM are significant challenges. Indeed, engineering training must be inclusive and diverse to reflect the global reality and ensure everyone has equal STEM opportunities. This includes the following:

Gender Equality: Historically, STEM careers have been dominated by men. Overcoming gender bias is an essential challenge. This implies eliminating gender stereotypes and prejudices in education and society. In addition, it is crucial to encourage girls' interest in STEM from an early age and provide female role models in these disciplines. Promoting an inclusive and discrimination-free learning environment is critical to encouraging women's participation in engineering and other STEM areas.

Racial and Ethnic Equity: Racial and ethnic diversity in engineering education is equally important. Many ethnic and racial groups are underrepresented in STEM. Promoting inclusion and equity in access to STEM education is crucial to address this issue. This may include implementing inclusive admissions policies and developing specific support programs for students from underrepresented groups.

Economic Accessibility: Another challenge to diversity in STEM is affordability. STEM careers often require significant educational investments, such as college tuition and expensive study materials. To overcome this obstacle, it is crucial to offer scholarship opportunities and financial support to students from all economic backgrounds.

Cultural Adequacy: Cultural diversity must also be addressed. STEM training programs must be culturally appropriate and sensitive to attract and retain students from diverse cultural backgrounds. This may involve adapting curricula and including diverse perspectives and examples in educational content.

Mentoring and Support: Mentoring is crucial in promoting diversity in STEM. Establishing mentoring programs that connect students from underrepresented groups with STEM professionals can provide role models, guidance, and emotional support that help overcome barriers.

C. Community Engagement

Collaboration with local communities and the involvement of educational institutions in STEM outreach initiatives are essential [10] [8]. This includes organizing workshops, events, and activities to engage the community and foster interest in STEM from an early age. Collaboration with local communities and the involvement of educational institutions in STEM outreach initiatives play a crucial role in promoting interest in science, technology, engineering, and mathematics from an early age [11]. This includes the following elements:

Educational Workshops: Hosting STEM workshops in local schools and elsewhere in the community can effectively bring students closer to these disciplines. These workshops can include hands-on activities, experiments, and engaging and challenging projects. Educators and STEM professionals may be invited to deliver these workshops to inspire young people.

Special Events: Hosting special STEM events, such as science fairs, technology expos, and robotics competitions, creates opportunities for students to showcase their projects and discover the potential of STEM careers. These events also encourage interaction between students, educators, and professionals, which can be very motivating.

After-School Programs: In schools or community centers, after-school STEM programs provide students additional space to explore their interests in these disciplines. These programs can include science clubs, robotics teams, programming classes, and more. They facilitate deeper learning and allow students to apply what they have learned in a practical context.

Talks and Conferences: Inviting STEM experts to give talks and lectures in schools or the community is another effective strategy. These talks can expose students to various areas of STEM and show them how these disciplines are related to everyday life and professional careers.

Mentoring: Establishing mentoring programs that connect students with professionals and college students in STEM gives young people role models and personalized guidance. Mentors can share their experiences, offer advice, and help students set educational and career goals.

Collaboration with Companies and Organizations: Educational institutions can collaborate with local businesses and organizations to organize STEM events and activities. This may include company visits, internships, joint projects, and sponsorship of educational activities. This collaboration can help students understand how STEM concepts are applied in the real world.

D. Effective Assessment

Measuring success in STEM education goes beyond grades. The assessment should assess deep understanding, practical application, and problem-solving skills [9]. Review in STEM should go beyond traditional qualifications and focus on deep knowledge, practical application, and problem-solving skills, as these are the critical aspects of preparing students for successful careers in science, technology, engineering, and mathematics. In addition, practical assessment in STEM should reflect these disciplines' collaborative and helpful nature.

IV. RESULTS

The analysis of the socio-academic variables presented by university students was made, finding the following information: 54% were men and 46% were women. According to the area of studies, 47.8% were students in the area of engineering and 52.2% in social sciences; in addition, the average age was 23 years with a standard deviation of 1.41 years in a range of 18 to 29 years, including to university students of all years and academic cycles. It was found that the level of social responsibility of the student and its dimensions is medium, with a tendency to be low (Table 1). The main difficulty students encounter is that there is no adequate training in social responsibility to apply it in society. Also, the student does not know many realities to commit to their environment, and the activities they perform as social responsibility are more helpful or social support.

Deep Understanding: Assessment in STEM should assess the depth of students' understanding rather than simply measuring their ability to memorize information. This means that tests and assessments should be designed to assess students' ability to explain concepts in their own words, connect ideas, and apply knowledge in different contexts.

Practical Application: One of the main goals of STEM education is to prepare students to apply their knowledge in real-world situations. Therefore, assessments should include practical problems and scenarios that require students to use their theoretical understanding to solve concrete situations. This can consist of projects, simulations, experiments, and case studies.

Problem-Solving: Problem-solving skills are essential in STEM. Assessment should measure students' ability to identify problems, develop strategies to address them, analyze data, and arrive at informed solutions. Questions and concerns in evaluations should be challenging and encourage critical and creative thinking.

Teamwork: In many STEM disciplines, collaboration is critical. Therefore, assessments may include teamwork components where students must collaborate on projects or solve problems. This assesses individual skills and students' ability to work effectively in groups.

Results Presentation: Effectively communicating findings and results is essential to STEM. Assessments may require students to present their findings clearly and concisely through written reports, oral presentations, or digital media. This assesses your ability to communicate scientific and technical information effectively.

Formative Assessment: Besides summative assessments (which measure learning at the end of a period), formative assessment is critical in STEM. This involves continuous feedback during the learning process. Educators can use regular feedback and formative assessments to help students identify areas for improvement and adjust their study approaches.

Learning Portfolios: Instead of relying solely on standard exams and tests, students can compile learning portfolios that include projects, assignments, reports, and reflections throughout their STEM education. This provides a holistic view of your progress and achievements.

Authentic Assessment: Authentic assessments involve the application of knowledge and skills in situations that mimic those in the real world. This may include solving problems based on real scenarios or creating practical solutions to current STEM challenges.

Overcoming these challenges in engineering education through properly implementing STEM methodologies is essential to prepare future professionals to face the constantly evolving technological and scientific challenges.

III. METHODOLOGY

In this work, a content analysis of publications from 2020 to the present has been carried out, which involves the necessary aspects of training students in engineering careers. It is intended to know if the incorporation of STEM methodologies influences the professional quality of the future engineer. In this sense, Table 1 shows the principal internationally recognized authors and their contributions to STEM methodologies for vocational training.

Table 1. Principal authors and their contributions to STEM methodologies.

Author(s)	Featured Publication	Main Focus
Linda Darling-Hammond[12]	"Preparing Teachers for a Changing World: What Teachers Should Learn and Be Able to Do"	It advocates teacher training that includes STEM teaching as an essential competency for modern education.
Mitchel Resnick[13]	"Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play"	It highlights the importance of creativity and play in STEM education, especially in inspiring young students.
John Hattie[14]	"Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement"	It examines the effectiveness of various pedagogical strategies on student achievement, including STEM-related ones.
Eric Mazur [15]	"Peer Instruction: A User's Manual"	It proposes active teaching methods like peer instruction to improve STEM comprehension.
Pamela McCauley-Bush [16]	"Ergonomics: Foundational Principles, Applications, and Technologies"	It advocates the inclusion of ergonomics and usability in the training of engineers, highlighting its relevance in STEM.

Note. p= p-value (0.05); Chi2= value of the statistic; Df= Degrees of freedom.

For the classification of these documents, the following criteria were taken into consideration:

Inclusion Criteria:

- Thematic Relevance: The articles had to deal with the importance of incorporating STEM methodologies in the training of engineers.
- Publication in Recognized Scientific Journals and Conferences: Inclusion of articles published in peer-reviewed scientific journals and renowned academic conferences.
- Publication Date: Articles published in the last five years.
- Geographic Focus: International studies were included.
- Type of Research: Qualitative and quantitative research, systematic reviews, meta-analyses, and case studies, among others, were considered, provided that they included aspects of this research.
- Educational Focus: Articles had to somehow address engineering education or engineering programs. Either from the levels of education such as undergraduate, graduate, or technical education.

Exclusion Criteria:

- Thematic Irrelevance: Articles that do not focus on the importance of STEM methodologies in engineering training were excluded.
- Non-Scientific Sources: Non-academic sources, such as unverifiable websites, personal blogs, or non-peer-reviewed sources, were excluded.
- Language: Articles that were not in Spanish or English were excluded.
- Old Publication Date: Works published outside five years were excluded.
- Duplicates: Duplicates or similar articles were avoided in the literature review.
- Lack of Access: Non-open access works were excluded.

IV. RESULTS

The results of the literature review on the teaching of physics in the training of engineers are presented with an overview of the results found:

Physics represents a fundamental basis in the training of engineers. The review showed how understanding physical principles is essential to success in engineering and how this discipline provides the theoretical foundation needed to tackle complex problems.

The different teaching methodologies used in training engineers in physics include traditional approaches, such as lectures and laboratories, and more innovative techniques, such as project-based learning or simulation teaching.

Identifying the challenges and obstacles engineering programs face when teaching physics is essential. This includes a lack of resources, a student understanding gap, or the need to improve pedagogy. It is observed that engineering schools tend to have high academic demands and little empathy between teachers and students.

The review provided an insight into the effectiveness of specific pedagogical strategies used in teaching physics to engineers; in this sense, the primary methods used in engineering training are simulations and experimental practices, project-based learning, case studies, and online resources.

Evaluating how teaching physics influences student performance and success in engineering programs is essential. Table 2 shows the contributions of physics in engineering and its participation in the training of engineers.

Table 2. Contributions of physics in engineering.

Aspects of Physics	Contribution in Engineering
Mechanics	It supports the design and analysis of structures, machines, vehicles, and mechanical systems. It helps to understand the movement, force, and tensions in objects and methods.
Thermodynamics	Essential in engineering power systems, such as engines, power plants, and oiling systems. It is also applied in industrial processes and heating and cooling systems.
Electromagnetism	It is based on electronics and electrical engineering, from circuit design to generating and transmitting electrical energy.
Optics	It is used in the design of imaging systems, such as cameras and microscopes, and technologies, such as fiber optics and optical sensing devices.
Waves and Sound	They are applied in telecommunications, acoustics, and the design of communication devices, such as antennas and speakers. It is also used in sonar and ultrasound technologies.
Materials and Properties	It helps select suitable materials for engineering applications, considering strength, conductivity, and durability properties.
Fluid dynamics	Essential in fluid systems engineering, from piping system planning to aerodynamics in the aerospace and automotive industry.

Research on new methodologies, technologies, or pedagogical approaches in physics education for engineers makes it possible to identify and report on these innovations and their potential impact. This shows that the contribution of physics helps train engineers to develop new technologies and innovations (Table 3).

Table 3. Engineering developments that include contributions from physics.

Engineering Innovation	Contribution of Physics
Lasers	Quantum physics is fundamental to understanding and developing lasers. These devices are used in various applications, from optical communication to medicine and manufacturing.
Positron Emission Tomography (PET)	This medical diagnostic technique relies on physical principles, such as positron emission and gamma radiation detection, to create three-dimensional images of the inside of the body.
Nanotechnology	Nanotechnology draws on principles of quantum physics and statistical mechanics to manipulate and design materials at the nanometer level, which has applications in electronics, medicine, and advanced materials.
Advanced Sensors	Sensors used in cars, airplanes, and medical devices, among others, are often based on physics concepts, such as measuring pressure, temperature, and light.
Magnetic Resonance Imaging (MRI)	MRI is a medical diagnostic technique that takes advantage of principles from the physics of nuclear magnetic resonance to obtain detailed images of soft tissues in the body.

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Table 4. Present and future trends for physics education.

Current Trends in Physics Education	Future Trends in Physics Education
Interdisciplinary Approach	Quantum Education
Active Learning	AI and Physics Integration
Educational Technology	Applied Quantum Physics
Focus on fundamental concepts.	Renewable Energy Education
Personalization of Learning	Global Project-Based Learning
Distance Education	Space Exploration and Physics
Inclusion of Experimental Methods	Nanotechnology and Physics
Formative Assessment	Focus on Quantum Technology
Focus on Problem-Solving Skills	Education in Sustainability and Climate Change
Inclusive and Diverse Education	Advanced Materials Physics
Focus on Communication Skills	Physics and Advanced Robotics
Sustainability and Renewable Energy	Data Science and Physics Education
	Development of New Materials

The review also identified areas where further research is needed. Table 5 shows the main areas where new research and development is required for engineering physics.

Table 5. Research areas for engineering.

Areas of Contribution to the Teaching of Physics for Engineers	
Development of New Educational Resources	Creation of simulations, virtual labs, and high-quality online content to improve the accessibility and interactivity of learning.
Interdisciplinary Approach	Integration of physics with other engineering disciplines and applied sciences to prepare engineers for multidisciplinary projects.
Personalization of Learning	Adaptation of teaching to the individual needs of students through technology and continuous feedback.
Practical Approach and Projects	Promotion of practical problem-solving and real engineering-related projects for a meaningful application of physics.
Advanced Educational Technology	Integration of advanced technological tools, such as virtual or augmented reality, to improve the understanding of complex physical concepts.

Other areas that could be of interest in the engineering areas and that focus on areas essential in current professional training and necessary for new professionals in the digitalized industry are presented in table 6. It is important to highlight that as progress technology and social characteristics are transformed, new areas may emerge that adapt to the realities of the moment and adapt to the demands of the professional of the future.

Table 6. Other areas of interest for the training of engineers.

Other areas of interest for the training of engineers	
Effective Formative Assessment	Development of assessment methods that provide helpful feedback and enable students to correct mistakes and improve their understanding.
Promoting Diversity and Inclusion	Implement strategies to attract and retain diverse students and eliminate gender bias in physics education.
Development of Communication Skills	It helps students communicate physical concepts and experiment results effectively for engineering success and interdisciplinary collaboration.
Quantum Education and Quantum Technology	Inclusion of quantum concepts in physics teaching to prepare engineers for growth in the field of quantum technology.
Teaching Emerging Issues	Preparation of engineers to address emerging issues such as sustainability, climate change, and cybersecurity through applied physics.
Continuous Teacher Training	They offer professional development programs for teachers to keep up with the latest trends and best practices in physics education.
Research in Physics Education	Conducting research in physics pedagogy to identify practical, evidence-based approaches to teaching physics to engineers.

CONCLUSIONS

1. A strong background in physics remains essential for engineers, as it provides a fundamental theoretical and conceptual foundation for understanding and addressing complex problems in various engineering fields.
2. Physics plays a crucial role in the digitized industry by supporting the development of advanced technologies, such as electronics, programming, artificial intelligence, and quantum technology.
3. Engineers with a background in physics can work on multidisciplinary projects, combining their knowledge of physics with digital and technological skills to tackle complex challenges.
4. Engineers with a background in physics are well known for their ability to innovate and problem-solve, making them valuable assets in the digital industry, where creativity and problem-solving are constantly required.
5. Understanding physical principles is essential to address sustainability and social responsibility issues in the digital industry, such as energy efficiency and data management.
6. Professionals in the digital industry must commit to continuing education to keep up with ever-evolving technological and scientific advances, including understanding the underlying physical principles.

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