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Use of Maple in the teaching of physics in engineering

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Abstract. - This paper presents a theoretical analysis of the use of new technologies in teaching physics in engineering careers. Special emphasis is made using Maple software, since it is an easy-to-use and free-access tool, which allows students to learn quickly and efficiently, besides providing potential graphic resources. The literature is reviewed and the main results and proposals for academic development that can favor physics teaching in engineering and technical careers are presented. The results reveal that technology in education is a significant alternative to creating spaces for group interaction and learning, which includes computational skills as a valuable resource for the new professional.

Keywords: ICT in education, Maple, engineering, physics.

Uso de Maple en la enseñanza de física en ingeniería

Resumen: En este trabajo se presenta un análisis teórico sobre el uso de nuevas tecnologías en la enseñanza de la física en las carreras de ingeniería, se hace especial énfasis en el uso del software de Maple, por ser este una herramienta de fácil utilización y de acceso libre, que les permite un aprendizaje rápido y eficiente a los estudiantes, además de brindar un potencial en recursos gráficos. Se revisa la bibliografía y se exponen los principales resultados y las propuestas de desarrollo académico que pueden favorecer la enseñanza de física en ingeniería y en aquellas carreras técnicas. Los resultados revelan que el uso de la tecnología en la educación es una alternativa significativa para crear espacios de interacción grupal y de aprendizaje, que incluya las habilidades computacionales como un recurso valioso en el nuevo profesional.

Palabras clave: TIC en la educación, Maple, ingeniería, física.

I. INTRODUCTION

The use of new technologies in the teaching of physics in engineering has significantly transformed the way students learn fundamental concepts, integrating digital tools that enhance both theoretical understanding and practical application [1]. In a field where a deep understanding of physical principles is essential for solving complex problems, the incorporation of technologies such as interactive simulations, virtual labs, web-based learning environments, and augmented reality platforms has proven to improve academic performance and foster more meaningful learning.

Various studies [1]-[3] have highlighted the relevance of these technological resources in engineering education. According to a study conducted in Brazil, the use of simulations in virtual learning environments has been effective in teaching classical mechanics, allowing students to visualize physical phenomena that would otherwise be difficult to observe in a conventional laboratory. Similarly, other research suggests that the use of augmented reality environments has improved the understanding of electromagnetic concepts in electrical engineering students [2]. These technologies allow interaction with three-dimensional representations of magnetic and electric fields, helping students develop a clearer intuition about abstract phenomena.

Other authors confirm that virtual laboratories have been widely adopted in the teaching of physics for engineering, being integrated into university programs to complement traditional laboratory experiences [4]. In this way, the use of these labs not only increases accessibility for students but also facilitates real-time experimentation, allowing the repetition of experimental scenarios without the limitations of time or physical resources. Additionally, virtual laboratories offer an opportunity to explore scenarios that may be dangerous or impossible to recreate in a physical environment.

A competency-based learning approach has also been a key trend in the use of technologies in physics teaching. Previous research has shown that the impact of interactive platforms and online tutorials, along with the flexibility of access to interactive content, allows students to adjust the learning pace to their own needs, promoting greater autonomy and improving results in final assessments [5]. This transition to a new learning model aligns with the demands of the labor market, which requires engineers capable of applying theoretical concepts to solve real-world problems using advanced technological tools.

With these premises, it is also recognized that the integration of artificial intelligence (AI) and machine learning in the teaching of physics is beginning to show great potential. Preliminary studies have explored the use of AI-based virtual tutors to personalize the learning of complex concepts such as thermodynamics and quantum mechanics [6]. These tutors can adapt explanations and lesson pacing according to each student's progress and difficulties, providing immediate feedback and increasing the retention of key concepts.

This work is organized by beginning with this introduction, which outlines the general topic, followed by a theoretical development that acknowledges the relevance of concepts associated with technology in physics teaching, then with the methodology describing the evaluation of academic and scientific documents, continuing with the presentation of results and conclusions. Technological tools in engineering education have not only allowed students to access new ways of interacting with physical principles but also transformed the pedagogical approach, aligning it with the needs of a more practical and competency-oriented training. The contributions made by different authors and countries highlight the importance of continuing to explore and expand the use of these technologies in higher education.

II. DEVELOPMENT

Education is evolving rapidly. In developed countries, the use of technologies in engineering is increasingly advancing with the incorporation of tools that facilitate the understanding of concepts, though they do not replace them. This means that through the use of technology, it is possible to delve even deeper into scientific topics and appreciate their relevance.

Some authors [7] address how digitalization is reshaping education and training to promote sustainability, highlighting the crucial role of information and communication technologies (ICT) in this process. Additionally, emphasis has been placed on the integration of digital technologies, such as data analytics, and how this can enhance teaching and learning, particularly in the field of engineering, allowing for a more inclusive and sustainability-oriented education. This approach is key to meeting the Sustainable Development Goals (SDGs) in education.

Khalid and others [8] highlight that technological tools offer significant opportunities to improve student motivation and engagement, particularly in interactive environments. Through digital simulations, virtual labs, and multimedia resources, students can explore scientific and engineering concepts more practically and experimentally, leading to a greater understanding of complex topics. However, barriers are also noted, such as the lack of equitable access to technology in developing countries, and the difficulties faced by teachers in adequately integrating technologies into the classroom, requiring continuous support and training to maximize their impact.

In the context of engineering education, digital technologies not only facilitate more dynamic learning but also allow for the personalization and adaptation of teaching to the individual needs of students. Through intelligent tutoring systems and learning analytics, instructors can tailor lessons to particular learning styles, providing precise feedback and improving academic performance. Nevertheless, the effective incorporation of these technologies still faces challenges, highlighting the importance of a balanced approach that considers both the development of digital competencies and equity in access to technological resources [8].

Authors like Martínez and others [9] discuss the digital transition in engineering education, emphasizing the importance of integrating remote laboratories to complement practical training, especially in a context where information and communication technologies (ICT) play a crucial role. The authors emphasize the importance of creating laboratory networks that allow students to remotely access real experiments, ensuring more flexible and accessible learning. Remote laboratories have a key advantage: they are accessible without time restrictions. Additionally, they reduce the need for costly equipment and provide students with the opportunity to repeat practices as often as necessary, improving their understanding of concepts. Furthermore, these laboratories offer greater safety compared to physical labs, minimizing the risks of accidents and damage to equipment. This approach also fosters autonomy in learning, as students can conduct practices without the need for constant supervision.

However, significant challenges were experienced by engineering professors in universities around the world during the COVID-19 pandemic, as online teaching became the only available solution to continue the educational process. Among them were technical issues, a lack of effective interaction with students, and difficulties in maintaining integrity in online assessments. Furthermore, the quality of technological resources, such as IT support and internet access, was unsatisfactory for most teachers, negatively affecting the delivery of content and the execution of practical activities like labs.

Despite these challenges, online education has proven to have important advantages, such as the flexibility to access recorded classes and the reduction of costs associated with mobility. However, the lack of adequate practical experience, especially in engineering courses that require an experimental approach, has been one of the major drawbacks. These premises reinforce the need to adopt hybrid approaches and strengthen investment in professional development for teachers to ensure a smoother transition to digital learning [10].

Tools like Maple have stood out as a powerful resource for learning and teaching in engineering, providing a symbolic and numerical environment that allows students to solve complex problems efficiently [11]. Its use in engineering education facilitates the understanding of advanced mathematical concepts, such as differential and integral calculus, linear algebra, and differential equations, by offering dynamic visualizations and simulations that reinforce conceptual learning. Maple not only helps students perform precise calculations but also fosters critical thinking by allowing them to explore different approaches to solving engineering problems.

Additionally, Maple has proven to be a valuable tool for simulating physical systems and mathematical modeling, which is crucial in engineering fields such as mechanics, electricity, and thermodynamics. Teachers have also found Maple to be an ally in designing activities that promote active learning, such as real-time problem-solving during classes. Maple's ability to handle large volumes of data and generate high-quality visual results makes it an ideal platform for research and project-based learning, making it indispensable for modern engineering education [12].

These are some of Maple's main features:

- **Symbolic calculation:** Maple can manipulate algebraic expressions symbolically, enabling operations such as derivatives, integrals, simplifications, and solving symbolic equations, which is useful for solving complex problems in engineering and mathematics.
- **Numerical calculation**: In addition to its symbolic capabilities, Maple also allows high-precision numerical calculations, such as solving differential equations, optimization, and dynamic system simulations.
- **Graphical visualization**: Maple offers advanced visualization tools that allow the plotting of functions in 2D and 3D, creating interactive animations, and visualizing complex data, which facilitates the understanding of mathematical concepts and physical phenomena.
- **Simulation and modeling**: Maple can simulate physical systems and perform mathematical modeling, which is essential in fields like mechanical, electrical, and thermodynamic engineering.
- **Intuitive interface**: Maple's environment is designed to be user-friendly for both beginners and experts, with an interactive graphical interface that allows the creation of rich documents with mathematical content.
- **Programming language**: Maple includes its own programming language, enabling users to create customized scripts and algorithms to solve specific engineering or research problems.
- **Specialized libraries**: Maple has extensive mathematical and scientific libraries, including functions for linear algebra, calculus, probability and statistics, differential equations, and more.
- **Integration with other tools**: Maple can integrate with other software platforms and data formats, such as MATLAB, Excel, LaTeX, and CAD tools, facilitating its use in an interdisciplinary environment.

III. METHODOLOGY

This study conducted a documentary analysis on the use of technologies in engineering programs. Sources published in high- and medium-impact journals, as well as academic materials from other categories, were reviewed. Tables 1 shows the works selected from the different sources.

Table 1. Sources consulted.

Title	Material Type	Indexation Type
Evaluating the learning process of mechanical CAD students using virtual reality [1]	Scientific article	Scopus
Virtual reality systems: A method to evaluate the applicability based on the design context [2].	Conference	Scopus
Personalized learning tool for thermodynamics [3].	Scientific article	Scopus
Intelligent Tutoring System Using Decision Based Learning for Thermodynamic Phase Diagrams [4].	Scientific article	Scopus
An experience in using metaverses for the teaching of mechanical physics to engineering students [5].	Scientific article	Latindex
Intelligent systems applied to teaching programming in engineering [6].	Conference	N/A
Re-engineering education and training: Fostering digitalization for sustainability [7].	Scientific article	Latindex
A systematic review: Digital learning in STEM education [8].	Scientific article	Scopus
The challenge of digital transition in engineering: A solution made from a European collaborative network of remote laboratories based on renewable energies technology [9].	Scientific article	Scopus
Online Mode of Teaching and Learning Process in Engineering Discipline: Teacher Perspective on Challenges Faced and Recommendations [10].	Scientific article	Scopus
MAPLE program and academic performance in Civil Engineering students, mathematics area [11].	Scientific article	Latindex
Mathematics didactics and cognition of differential equations assisted by Maple 17 for civil engineering students [12].	Thesis	N/A
Tools for learning mathematics in engineering with Maple [13].	Thesis	N/A
Assistance of mathematical software in the study of differential calculus in engineering students [14].	Scientific article	Latindex

This selection of material was conducted considering the following inclusion criteria:

- The document considered the use of technology in engineering education.
- The document was published in recent years.
- The document outlined a clear methodology.
- The document was open Access.
- The document was written in either English or Spanish.

Additionally, an analysis was carried out to understand how technology is impacting the way engineering careers are taught in different countries around the world. The analysis also examined the impact of these technologies on the future professional landscape.

IV. RESULTS

Once analyzed the documents, the following was confirmed:

The main works published in recent years (2019 to present) have been received by journals indexed in Scopus (figure 1). It is observed that the number of publications has considerably decreased in recent years. This may be because the use of technologies in engineering education is now considered a common practice that has gained ground as a natural part of the discipline, rather than an innovation.

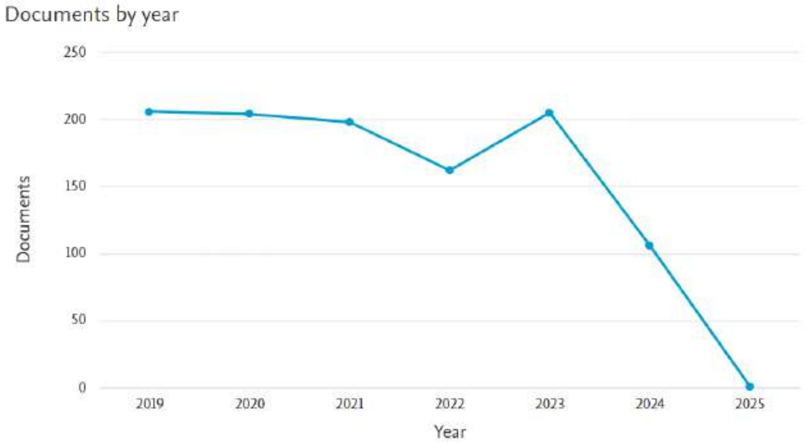

Fig. 1. Documents published per year in high-impact journals.
Source: [15].

Another aspect analyzed was the international affiliation of universities, noting that the institutions leading in the number of publications are Kherson State University and The Bulgarian Academy of Sciences, with about 10 documents each (fig. 2). These universities have been very active in research on technology applied to engineering education. Other notable institutions include Universitas Pendidikan Indonesia, Universitat Politécnica de Catalunya, and Tecnológico de Monterrey, which have a similar number of publications, around 8 documents. This indicates strong participation from these universities in the research and development of methodologies and technological tools to enhance engineering education.

In a lower range, with approximately 7 documents, are the Institute of Information and Communication, Lapin ammattikorkeakoulu, and Universiti Kebangsaan Malaysia. Finally, with a slightly lower number of publications is the Instituto Politécnico do Porto. These data reflect a global trend in researching technology applied to engineering education, where several institutions from different countries are significantly contributing to the development of the field. The variety of institutions involved, from Europe, Asia, and Latin America, underscores the global interest in improving teaching methods in engineering through the use of advanced technologies, suggesting that this is a topic of great international relevance.

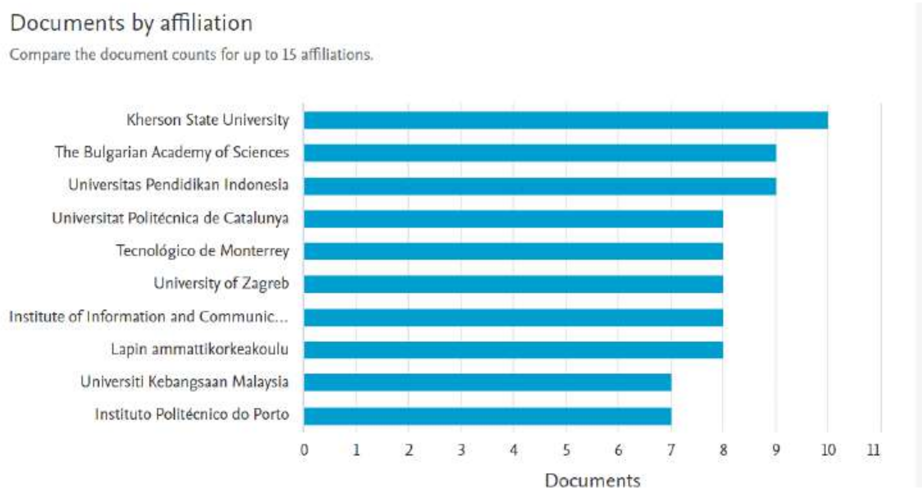

Fig. 2. Main affiliations observed in the publications.
Source: [15].

On the other hand, it was observed that conference articles are the predominant type of document, representing 62.9% of the total, with 681 documents. This suggests that much of the research in this field is presented and discussed at conferences, reflecting the importance of these events for disseminating new knowledge and advances in engineering education.

Scientific articles represent 27.9% of the total, with 302 documents, indicating a solid output in academic journals. This type of document is essential for the validation and peer review of advancements in the use of technology in engineering education. Other types of documents, such as book chapters (40 documents, 3.7%) and conference reviews (34 documents, 3.1%), have a smaller representation but remain relevant. Book chapters reflect an interest in offering broader approaches or collaborations that include multiple authors, while conference reviews compile advancements and discussions from academic events. Additionally, a marginal number of other types of documents were observed, such as reviews (18 documents, 1.7%), books (2 documents), errata, retracted documents, and one editorial, which together represent less than 1% of the total. These documents provide additional context to the advancements and also correct or adjust the published content.

Other observed results show that the use of remote laboratories in engineering programs is a powerful teaching tool, highlighting that simulations allow students to interact responsibly with engineering designs without risking equipment and personnel. However, achieving this requires adequate infrastructure that supports its application. Moreover, one of the most consistent findings is that the use of Maple significantly improves students' understanding of advanced mathematical topics, such as calculus, linear algebra, and differential equations. Studies have shown that students who use Maple tend to grasp abstract concepts better through graphical visualization and symbolic computation that the software facilitates.

Maple has been widely used in engineering courses to foster the development of analytical and problem-solving skills. By allowing students to experiment with different approaches to solving mathematical or simulation problems, Maple encourages a more exploratory learning environment. Students can evaluate different scenarios and verify the results of their solutions, enabling deeper and more autonomous learning. In this sense, engineers need to conduct simulations of physical systems and model complex phenomena. Maple has proven to be an effective tool in this regard, allowing students to create models of dynamic systems (such as control systems or electrical circuits) and simulate their behavior in real-time. This simulation capability not only enhances theoretical understanding but also allows for visualizing the effects of changes in system parameters, something that would be difficult to achieve with traditional methods.

Another important finding is that Maple helps students reduce the time required to perform complex calculations, enabling them to focus on interpreting the results and applying them to engineering problems. Instead of spending time on manual calculations that may be prone to errors, students can delegate these calculations to the software and instead concentrate on conceptualization and critical analysis. Several studies have found that the use of Maple in engineering classrooms increases student motivation and, consequently, improves their academic performance. Students reported feeling more engaged and motivated when using technological tools like Maple that allow them to interact more directly with concepts. In some cases, performance in exams and projects improved due to a stronger understanding of theoretical foundations.

A highlighted finding is that to maximize the benefits of using Maple, studies have shown that it is crucial to adequately train teachers in the use of the software. Those teachers who master Maple and effectively integrate it into their lessons provide a better learning experience for their students. This training enables teachers to design more enriching activities and problems, making the most of the software's capabilities.

CONCLUSIONS

Applied technologies, such as remote laboratories and interactive simulations, allow engineering students to access practical learning environments, even remotely, improving their understanding of complex concepts without the need for physical infrastructure. In this way, tools like Maple provide advanced 2D and 3D visualizations that help students intuitively grasp complex mathematical and engineering problems, enhancing their ability to solve differential equations, linear algebra, and simulations of physical systems.

The implementation of active methodologies, such as Peer Instruction combined with the use of ICT, fosters the development of critical thinking, collaboration among students, and increased participation in engineering classrooms. Thus, the use of Maple and other technologies enables a more flexible and personalized teaching approach, where students can progress at their own pace and repeat simulations or exercises, enhancing their mastery of concepts.

Moreover, the combination of active learning with digital tools, such as simulations with Maple, has been shown to increase long-term knowledge retention compared to traditional passive teaching methods, which is crucial in technical disciplines like engineering. Additionally, platforms like Maple, along with online learning and digital resources, promote students' self-efficacy by allowing them to explore different approaches and solutions to engineering problems, better preparing them for real-world situations.

Similarly, digital technologies, including software like Maple, help create a more dynamic and interactive learning environment that increases students' interest and motivation, making learning more engaging and accessible. Despite these advancements, the adoption of technologies like Maple faces challenges in developing countries due to a lack of access to quality technological resources and the need to train teachers in the effective use of these tools. In this context, Maple provides a robust environment for real-time simulation and modeling of physical systems, allowing students to experiment with diverse scenarios and evaluate different solutions, enhancing their ability to model real-world engineering problems. The use of these technologies in engineering education better prepares students for the workforce by teaching them to use tools they will encounter in the industry, promoting efficient and effective problem-solving.

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