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STEM methodologies and their importance in engineering training: a Scoping Review

Metodologías STEM y su importancia en la formación de ingenieros: una revisión de alcance

Metodologias STEM e a sua importância na formação em engenharia: uma Revisão do Âmbito de Aplicação

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Abstract

This paper presents a bibliographic analysis of STEM methodologies in the training of engineers. For this, some scientific articles have been analyzed to know the new trends in engineering for their contribution to modern industry and the development of new technological proposals that contribute to the solution of social needs. In this sense, a brief and concise review has been made without depth to evaluate the trends required by industry 4.0 for new engineering professionals and how this should influence the educational reforms of the training of engineers. The main results show that education in polytechnic schools must readjust their profiles and curricular meshes so that future professionals can be competitive in the digitized industry.

Key words: : engineering, industry 4.0, STEM methodologies.

Resumen

Este trabajo presenta un análisis bibliográfico de las metodologías STEM en la formación de ingenieros. Para ello, se han analizado algunos artículos científicos para conocer las nuevas tendencias en ingeniería por su contribución a la industria moderna y al desarrollo de nuevas propuestas tecnológicas que contribuyan a la solución de necesidades sociales. En este sentido, se ha realizado una breve y concisa revisión sin profundidad para evaluar las tendencias que requiere la industria 4.0 para los nuevos profesionales de la ingeniería y cómo esto debe influir en las reformas educativas de la formación de ingenieros. Los principales

resultados muestran que la educación en las escuelas politécnicas debe reajustar sus perfiles y mallas curriculares para que los futuros profesionales puedan ser competitivos en la industria digitalizada.
Palabras clave: : ingeniería, industria 4.0, metodologías STEM.

Abstrato

Este documento apresenta uma análise bibliográfica das metodologias STEM na formação de engenheiros. Para tal, foram analisados alguns artigos científicos para conhecer as novas tendências da engenharia pela sua contribuição para a indústria moderna e o desenvolvimento de novas propostas tecnológicas que contribuem para a solução das necessidades sociais. Neste sentido, foi feita uma breve e concisa análise sem profundidade para avaliar as tendências exigidas pela indústria 4.0 para os novos profissionais da engenharia e como isto deve influenciar as reformas educacionais da formação de engenheiros. Os principais resultados mostram que a educação nas escolas politécnicas deve reajustar os seus perfis e malhas curriculares para que os futuros profissionais possam ser competitivos na indústria digitalizada.
Palavras-chave: : engenharia, indústria 4.0, metodologias STEM.

INTRODUCTION

STEM (Science, Technology, Engineering, and Mathematics) methodologies are an innovative educational approach that has become increasingly popular in schools and universities worldwide. This methodology seeks to promote learning through problem-solving, exploration, and experimentation, integrating different areas of knowledge to offer a more complete and relevant education. The main objective of STEM methodologies is to foster critical thinking and the development of skills and competencies necessary to face the challenges of today's world. By promoting the integration of natural sciences, technology, engineering, and mathematics, this methodology seeks to develop in students a deeper and more complete understanding of natural and technological phenomena and the skills necessary to design, build, and program solutions to complex problems. (Akiri, Tal, Peretz, Dori, & Judy, 2020) (Lena, Lauer, Kuhn, Wehn, & Ulber, 2023) (García-Tudela & Marín-Marín, 2023)

One of the main benefits of STEM methodologies is that they provide education more relevant to students' daily lives, allowing them to better explore and understand the world around them. In addition, this methodology encourages teamwork, collaboration, and creative thinking, essential skills for success in professional and personal life. Another vital benefit of STEM methodologies is their fostering of equity and inclusion in the classroom. By integrating diverse areas of knowledge, this methodology enables students from different cultural and socioeconomic backgrounds to participate on equal terms, thus promoting diversity and equal opportunities in education. (Peters-Burton, Kathleen Provinzano, & May, 2022) (Martínez-Borreguero, Naranjo-Correa, & Mateos-Núñez, 2022)

In this sense, STEM methodologies offer a more comprehensive and relevant education for students, encouraging the development of skills and competencies essential for success in personal and professional life and equity and inclusion in the classroom. By adopting this methodology, educators can help prepare students to meet the challenges of today's and tomorrow's world and thus contribute to developing a more informed, innovative, and sustainable society. STEM methodologies have a fundamental role in engineering schools, as they allow students to develop the skills and competencies necessary to meet the challenges of modern engineering. By integrating natural sciences, technology, engineering, and mathematics, these methodologies allow students to acquire theoretical and practical knowledge in programming, electronics, mechanics, and robotics, among others. (Hubinský, Legény, & Špaček., 2022) (Ambrož, Pernaa, Haatainen, & Aksela., 2023) (Kanaki & Kalogiannakis, 2022)

In engineering schools, STEM methodologies are applied through hands-on projects and activities that enable students to experiment, design, and build solutions to complex problems. In this way, students can apply the knowledge acquired in the classroom in real situations, developing practical and problem-solving skills (Jeong, González-Gómez, & Yllana-Prieto, 2020). In addition, STEM methodologies in engineering schools encourage collaboration and teamwork, essential skills in the field of engineering. Students work in teams to design and build solutions to complex problems, allowing them to develop the leadership, communication, and collaboration skills needed for teamwork. Finally, STEM methodologies are crucial in engineering schools because they encourage innovation and creativity. By promoting problem-solving and experimentation,

students can develop new solutions and technologies that contribute to the advancement of engineering.

Some authors claim that STEM methodologies have a fundamental role in engineering schools, as they allow students to develop the skills and competencies necessary to face modern engineering challenges. Furthermore, by integrating natural sciences, technology, engineering, and mathematics, these methodologies enable students to acquire theoretical and practical knowledge in critical areas, foster collaboration, innovation, and creativity, and prepare students for a career in engineering. (Arévalo, Cantera, García-Marina, & Alves-Castro, 2021)

This paper reviews ten scientific articles on the importance of STEM methodologies for engineering education to know the fundamental elements necessary in training the new engineers of the future. The industrial future is envisioned with high digital and multidisciplinary content, so engineering schools must reform their curricula so that new professionals have a new vision of their participation in modern industry.

Teaching in engineering schools has evolved significantly over time. In its beginnings, engineering teaching focused on transmitting theoretical knowledge and mathematical concepts. However, the need to incorporate more practical and experimental methodologies into the teaching process became evident over time. In the 1960s, the industrial engineering approach emerged, focusing on optimizing processes and improving production efficiency. This approach prompted the integration of computer science into engineering education, using simulation and modeling tools for systems design and analysis (Akiri, Tal, Peretz, Dori, & Judy, 2020) (Ambrož, Pernaa, Haatainen, & Aksela., 2023). (Lena, Lauer, Kuhn, Wehn, & Ulber, 2023)

In recent decades, teaching in engineering schools has evolved towards a more practical approach based on solving real problems. It has led to the incorporation of STEM methodologies in engineering education, where various areas of knowledge are integrated to foster creativity, innovation, and student collaboration. In addition, with the growing demand for highly trained engineers, engineering schools have begun to focus on training soft skills, such as communication, leadership, and collaboration. These skills are fundamental for engineers in the business world and allow them to work effectively in interdisciplinary teams. Another essential aspect in the evolution of teaching in engineering schools has been the inclusion of sustainability and social responsibility as cross-cutting issues in the

training of engineers. Engineers have a critical role in creating sustainable solutions and improving social welfare, and engineering schools are increasingly committed to training socially and environmentally conscious engineers. (Jeong, González-Gómez, & Yllana-Prieto, 2020) (Kanaki & Kalogiannakis, 2022) (Peters-Burton, Kathleen Provinzano, & May, 2022)

In this sense, teaching in engineering schools has evolved towards a more practical, interdisciplinary, and problem-solving approach. In addition, it has focused on forming soft skills and including sustainability and social responsibility as fundamental issues in the training of engineers. These changes reflect the need to train highly trained engineers committed to creating sustainable solutions and social welfare.

Teaching in engineering schools today

Today, teaching in engineering schools continues to evolve to adapt to the needs of the market and the challenges of the contemporary world. Some of the advantages and disadvantages of teaching in engineering schools today are as follows:

Advantages:

1. Practical approach: Teaching in engineering schools focuses on solving real problems and working on practical projects. It allows students to develop skills and competencies valuable to them in their professional careers.
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Disadvantages:

1. Heavy academic load: Teaching in engineering schools is known to have a heavy academic load due to the number of technical subjects that must be covered. It can be overwhelming for some students.

2. Competitiveness: Teaching in engineering schools can be highly competitive due to the demand for highly trained engineers. It can create an environment of stress and pressure among students.
3. Low diversity: Teaching in engineering schools is still predominantly male and underrepresented by ethnic and gender minorities. This can lead to additional barriers and challenges for students who do not fit this profile.
4. Cost: Teaching in engineering schools can be expensive due to the investment in technology and materials needed for student training. It may limit access to higher education for some students due to their economic situation.

Finally, it is possible to affirm that teaching in engineering schools today has advantages and disadvantages. Therefore, engineering schools must continue to evolve to address these challenges and ensure that students receive quality training to meet the challenges of the contemporary world effectively and responsibly.

2.2. STEM methodologies in industry 4.0

STEM (Science, Technology, Engineering, and Mathematics) methodologies have become a key topic in industry 4.0. Highly trained professionals in these areas are needed to face the challenges of the fourth industrial revolution. According to a report by the European Commission, it is expected that by 2025, 75% of jobs will require STEM skills. However, there is currently a skills gap in these areas, meaning a high demand for STEM-trained professionals exists.

In addition, the report highlights that STEM professionals are needed in industry and other sectors, such as healthcare and energy. The demand for STEM professionals in these sectors is expected to increase by 14% and 20% in the coming years. On the other hand, a UNESCO report points out that, globally, only 35% of students in STEM areas are women. It means there is a gender gap in these areas and that additional effort is needed to encourage women's participation in education and the STEM industry.

However, there are also exciting initiatives in the international arena to promote STEM education. For example, China's National STEM Education Program, launched in 2016, aims to increase the number of graduates in STEM areas and improve the quality of STEM education in the country. In summary, STEM methodologies are fundamental in Industry 4.0, and the demand for professionals trained in these areas is expected to increase significantly in the coming years. However, it is also essential to address the skills and gender gap in these areas at the international level to ensure that the

necessary resources are in place to effectively face the challenges of the contemporary world.

Some interesting facts about STEM methodologies in engineering education are:

- According to a report by the European Commission, by 2025, 75% of jobs are expected to require STEM skills.
- The skills gap in STEM is a global problem. For example, in the United States, there is expected to be a shortfall of 2.4 million workers with STEM skills by 2028, according to a report from the Education and Workforce Research Center.
- The UNESCO report I mentioned earlier highlights the gender gap in STEM areas. According to the report, only 35% of students in STEM areas are women.
- China's National STEM Education Program mentioned earlier, aims to increase the number of graduates in STEM areas in the country. According to a UNESCO report, China produces the most significant number of STEM graduates globally, with more than 4.7 million in 2016.

STEM methodologies in Latin American countries

In Latin America, engineering education also focuses on implementing STEM methodologies. Countries in the region are beginning to recognize the importance of training students in these areas to prepare them for Industry 4.0. According to a report by the Inter-American Development Bank (IDB), Latin American countries have fewer graduates in engineering and science careers. The report highlights the need to increase the quality of education in these areas to meet the demand for STEM professionals in the region. Many countries are implementing STEM education programs in schools and universities to achieve this. For example, the "Science for All" program in Mexico promotes STEM education in primary and secondary schools. In addition, the Mexican government has launched a program called "Youth Building the Future," which offers STEM skills training to young people in the region. (Inter-American Development Bank, 2022) (CONACYT, 2021)

In Colombia, the "Colombia STEM" program seeks to promote STEM education throughout the country. The program focuses on improving the quality of education in these areas and increasing the number of students choosing STEM careers. In (STEM education Colombia, 2022) this sense, Latin American countries are beginning to recognize the importance of STEM methodologies in engineering

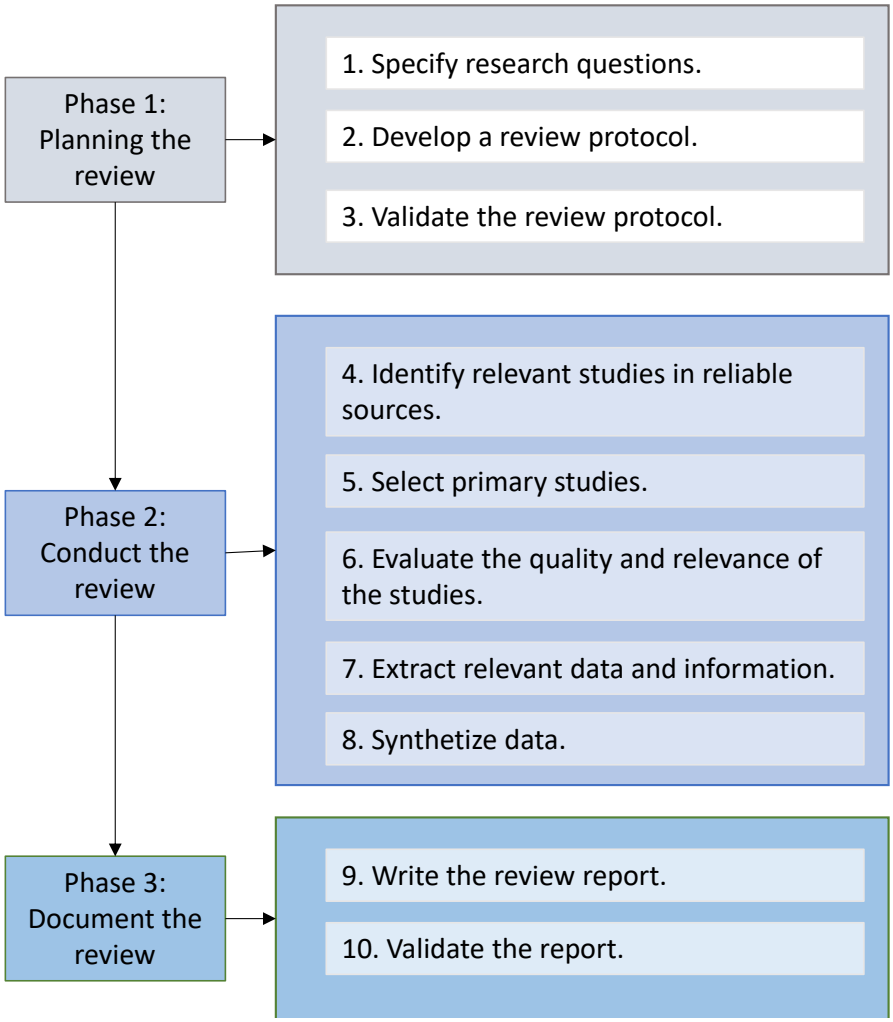
education and are implementing programs to promote education in these areas. Successful implementation of these programs can help close the STEM skills gap in the region and prepare students to meet the challenges of Industry 4.0.

MATERIALS AND METHODS

In this work, a non-in-depth literature review was carried out to know the characteristics of STEM methodologies for engineering education and their incorporation into industry 4.0 to initiate new research. Scientific articles from primary sources were evaluated, which show aspects of interest for formulating new proposals that help strengthen engineering studies and new professionals with a view to active participation in modern industry. Figure 1 presents the characteristics of the sources made, taking into account the sources and the contributions they offer.

The research carried out is simplified, with the fundamental purpose of evaluating the conceptual knowledge, theories, or characteristic elements of STEM methodologies in the training of engineers for industry 4.0. To this end, the methodology proposed by Kirtchenham and Okoli, and Schabram [9] on desk review, which in practice is similar to the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Anayses) review model, was considered. The proposed method consists of three phases: planning, development, and reporting of the systematic review, which are carried out following eight steps for its execution: determine the purpose of the review; define the protocol and training; perform literature search; screening for inclusion; quality assessment; data extraction; Synthesis of the studies and writing of the review.

Figure 1. Methodology proposed by Kirtchenham and Okoli and Scharamb(Tebes, Peppino, Becker, & Olsina, 2019) .



Phase 1: In this phase, the research questions have been defined, considering the relevance and timeliness of the topic of study. In this sense, the questions posed are:
Q1: How do STEM methodologies participate in Industry 4.0?
Q2: How do STEM methodologies look like in engineering training for Industry 4.0?
Q3: What variables have been considered in the new methodological proposals in engineering education?

The search process consists of researching scientific documents that allow finding studies related to the subject of study, specifically in teaching methodologies for industry 4.0 and engineering contributions. Although in addition, the search is limited to the most recent years, from 2020 to 2023, as it is a current topic. It is intended to analyze the new proposals of STEM methodologies for engineering in the digitized industry. The Scopus database and the publications of the Elsevier publishing house that were open access were used.

A first search chain was defined based on the title, and central field of the subject studied. Then, with these elements, the search chain is redefined considering the titles found, the keywords, and the referenced studies to achieve the following search chains finally:

• STEM AND methodology AND for AND industry 4.0 (4 documents)
• STEM AND education AND in AND engineering (98 documents)
• STEM AND methodology AND engineering (60 documents)

In table 1, the first results found in different Scopus journals are sampled, only in the year 2023.

Table 1. *Journals that have published the topic of study.*

Journal	Number of articles
Education Science	158
Applied Science	4

The manuscripts analyzed were classified according to the year of publication, in addition to the journal where it was published, the corresponding database, the number of citations, the methodology used, where experimental research, industrial case studies, and bibliographic reviews had priority.

The primary research was carried out through a chain of queries based on the research questions. The purpose was to know the articles' conclusions and the topics' quality. Four criteria were applied: population, intervention, comparison, and outcome (PICO). In this sense, the population refers to published studies. The intervention is related to STEM methodologies and the training of engineers for industry 4.0. The comparison refers to carefully selected studies with STEM methodologies and the type of research. The result includes published studies on the subject and new educational proposals for engineering; based on PICO, five new

questions were asked to ensure the quality of the extracted articles, as shown in Table 2.

Table 2. Evaluation of the quality of the documents analyzed.

Quality Control (QA)	Quality Assessment Questions	Answer
QA1	Does the paper describe the contributions of STEM methodologies in industry 4. 0?	(+1) Yes/ (+0) No
QA2	Does the document specify the characteristics of STEM methodologies for engineering education?	(+1) Yes/ (+0) No
QA3	Does the paper present any discussion of the findings surrounding STEM methodologies and their proposals in engineering education?	(+1) Yes/ (+0) No
QA4	Are the limitations present in STEM methodologies in engineering considered?	(+1) Yes/ (+0) No
QA5	Are future projections made for the inclusion of STEM methodologies in engineering schools?	(+1) Yes/ (+0) No

The inclusion and exclusion criteria aim to find important primary documents to answer the research questions posed. The agreement between the evaluators was resolved by applying Cohen's Kappa coefficient = 0.5 with a percentage of agreement of 86.3%. This value implies a moderate agreement among the evaluators.

The inclusion criteria were: that the preliminary research is associated with publications in journals on the contributions of STEM methodologies in the training of engineers for industry 4.0, that the year of publication is recent, between the years 2020 to 2023, that the document is presented in a high impact journal, preferably in English. While the exclusion criteria were: the preliminary study is not extensive, literature review articles, and similar articles from different sources.

RESULTS

Identifying the most effective STEM methodologies for engineering training: Research could compare different STEM methodologies, such as project-based learning, problem-solving, design, and experimentation, among others, and determine which are most effective in improving engineers' skills and competencies. Improving students' skills in STEM: Research could demonstrate how using STEM methodologies can improve students' understanding and performance in math, science, technology, and engineering. It could improve the quality of engineers' training and their ability to solve complex problems.

Improving student retention in STEM: Research could demonstrate how STEM methodologies can improve student retention in areas such as engineering, where there is a high dropout rate. Improving the quality of training and making it more exciting and attractive to students could improve student retention in STEM careers.

Identifying barriers to using STEM methodologies: Research could identify barriers and challenges educators and institutions face when implementing STEM methodologies in engineering training. By understanding these challenges, strategies could be developed to overcome them and improve the implementation of these methodologies. Assessing the long-term effects of STEM methodologies: Research could assess the long-term impact of STEM methodologies on engineering training, for example, how they influence their career and their ability to address future technological and societal challenges. It could justify the investment in implementing these methodologies in the training of engineers.

CONCLUSIONS

STEM methodologies are effective in improving the skills and competencies of engineers: if research finds that STEM methodologies are effective in improving the quality of training and skills of students in areas such as mathematics, science, technology, and engineering, it could be concluded that these methodologies are a viable option for engineering training.

Specific strategies are required to implement STEM methodologies: if research finds barriers to implementing STEM methodologies in engineering training, specific strategies are required to overcome these challenges. For example, it could include training for educators,

resources for implementing these methodologies, and careful planning to integrate them into existing training programs.

Implementing STEM methodologies can improve student retention in STEM careers: If research finds that STEM methodologies can improve student retention in STEM careers, implementing these methodologies is an important strategy to address talent shortages in critical areas such as engineering.

More research is needed to assess the long-term impact of STEM methodologies: If research finds that more research is needed to assess the long-term impact of STEM methodologies on engineering training, one might conclude that there is a need to continue researching and evaluating these methodologies to understand their long-term effects better.

Finally, STEM methodologies for engineering training can help guide the planning and implementation of engineering training programs and improve the quality of STEM training in general.

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