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# 3D printing in education as a strategy to strengthen STEAM competencies: a systematic review

*Impresión 3D en educación como estrategia para el fortalecimiento de competencias STEAM: una revisión sistemática*

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## Abstract

3D printing has gained increasing relevance in educational contexts as a resource to support teaching and learning processes aimed at the development of STEAM competencies. In this context, the objective of the present study was to systematically analyze recent scientific production on the educational use of 3D printing, identifying thematic trends and predominant pedagogical approaches within the specialized literature. To this end, a systematic review of documents indexed in the Scopus database was conducted, considering a final corpus of 662 publications corresponding to the period 2020–2025, selected through sequential exclusion criteria based on year of publication, subject area, and document type. The analysis was carried out at the level of abstracts and author keywords, which made it possible to address a large corpus without resorting to full-text analysis, in accordance with the objectives of the study. The methodological strategy included a qualitative analysis aimed at identifying recurring thematic axes. The results reveal a predominance of studies related to engineering education and additive manufacturing, in which 3D printing is primarily conceived as a tool for design-based learning and prototyping. In addition, a growing presence of pedagogical approaches associated with active learning and the STEAM paradigm is observed, although the integration of artistic and creative dimensions remains limited. Overall, the findings suggest a transition from an instrumental perspective toward more pedagogically oriented approaches, opening opportunities for future research aimed at a more balanced implementation of STEAM education.

**Keywords**: educational technology, active learning, science education

## Resumen

La impresión 3D ha adquirido una creciente relevancia en el ámbito educativo como recurso para apoyar procesos de enseñanza y aprendizaje orientados al desarrollo de competencias STEAM. En este contexto, el objetivo del presente estudio fue analizar de manera sistemática la producción científica reciente sobre el uso educativo de la impresión 3D, identificando tendencias temáticas y enfoques pedagógicos predominantes en la literatura especializada. Para ello, se realizó una revisión sistemática de documentos indexados en la base de datos Scopus, considerando un corpus final de 24 publicaciones correspondientes al período 2020–2025, seleccionadas mediante criterios secuenciales de exclusión por año de publicación, área temática y tipo de documento. El análisis se desarrolló a nivel de *abstracts* y palabras clave de autor, lo que permitió abordar un corpus amplio sin recurrir al análisis de textos completos, en coherencia con los objetivos del estudio. La estrategia metodológica incluyó un análisis cualitativo orientado a la identificación de ejes temáticos recurrentes. Los resultados evidencian un predominio de estudios vinculados a la educación en ingeniería y a la manufactura aditiva, donde la impresión 3D es concebida principalmente como una herramienta para el aprendizaje basado en el diseño y el prototipado. Asimismo, se observa una presencia creciente de enfoques pedagógicos asociados al aprendizaje activo y al paradigma STEAM, aunque con una integración aún limitada de las dimensiones artísticas y creativas. En conjunto, los hallazgos sugieren una transición desde una visión instrumental hacia enfoques más pedagógicos, abriendo oportunidades para futuras investigaciones orientadas a una implementación STEAM más equilibrada.

**Palabras clave**: tecnología educativa, aprendizaje activo, educación científica

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## Introduction

Within the broader transformation of contemporary educational systems, the development of complex competencies has become a central objective of pedagogical policies and practices worldwide. In this context, the STEAM framework has emerged as an integrative approach that brings together science, technology, engineering, arts, and mathematics, fostering interdisciplinary learning oriented toward real-world problem solving and critical thinking. This paradigm not only responds to the demands of the twenty-first-century labor market but also seeks to prepare students who can understand and engage reflectively with highly dynamic social and technological environments (Yakman, 2008; Quigley & Herro, 2016; Awad & Barak, 2014).

The integration of emerging technologies in education expands the possibilities for effectively implementing the STEAM approach, supporting active, student-centered methodologies. Among these technologies, 3D printing stands out for its capacity to materialize abstract concepts, facilitate experimentation, and promote design- and construction-based learning processes. Numerous studies maintain that the pedagogical use of additive manufacturing contributes to the development of higher-order cognitive skills, including spatial visualization and three-dimensional reasoning, while also increasing student motivation and engagement (Berman, 2012; Huang & Lin, 2017; Henriksen et al., 2017).

From a didactic standpoint, 3D printing aligns consistently with pedagogical approaches such as project-based learning and problem-based learning, both of which emphasize students' active participation in constructing their own knowledge. The specialized literature shows that integrating these methodologies with digital fabrication technologies fosters conceptual understanding, collaborative work, and the practical application of disciplinary knowledge, particularly in engineering and technology education contexts (Kolodner et al., 2003; Simpson et al., 2017; Kelley & Knowles, 2016). Nonetheless, recent studies indicate that its potential extends beyond these fields, allowing for incorporation into interdisciplinary educational experiences consistent with the STEAM framework (Henriksen et al., 2019; Martín-Páez et al., 2019).

In higher education and technical training, 3D printing is widely used to strengthen design, prototyping, and manufacturing processes, contributing to a tighter integration between theory and practice. However, in Latin American educational contexts, its adoption remains gradual and uneven, constrained by infrastructure limitations, access to technological resources, and teacher training. Even so, various regionally reported experiences indicate that when this technology is integrated in a planned and context-sensitive manner, it can generate meaningful learning and foster the development of transversal competencies associated with the STEAM paradigm (Gebhardt & Hötter, 2016; Calva-Chávez et al., 2025; Espinoza et al., 2024; Trust, 2017).

Despite growing academic interest in the educational use of 3D printing, the available scientific literature exhibits considerable thematic and methodological dispersion, making it difficult to identify clear trends and knowledge gaps. In particular, there is a prevalence of studies with technical and applied orientations, while pedagogical, interpretive, and context-sensitive analyses remain scarce. This situation points to a relevant research problem: the lack of systematic synthesis that would allow for an understanding of how recent literature conceptualizes the educational role of 3D printing and its contribution to the development of STEAM competencies.

Under these circumstances, a systematic literature review that organizes, synthesizes, and interprets the available evidence is warranted. The general objective of the present study is therefore to systematically analyze scientific production indexed in the Scopus database for the period 2020–2025, using a qualitative approach centered on the analysis of abstracts and author keywords. In this way, the study aims to identify thematic trends, predominant pedagogical approaches, and underexplored areas, offering a structured overview of the current state of research while guiding future pedagogical proposals and lines of inquiry related to strengthening STEAM competencies (Tranfield et al., 2003; Aria & Cuccurullo, 2017).

## Methodology

This study was developed under a qualitative approach, through a systematic review of the scientific literature aimed at analyzing recent academic production on the educational use of 3D printing and its contribution to strengthening STEAM competencies. From a research design perspective, the work operates at a descriptive-interpretive level, as it seeks to characterize trends, pedagogical approaches, and prevailing discourses in the specialized literature, without establishing causal or predictive relationships. The research design is non-experimental, observational, and cross-sectional, since it analyzes already-published scientific documents within a defined time frame, without direct intervention on the study variables.

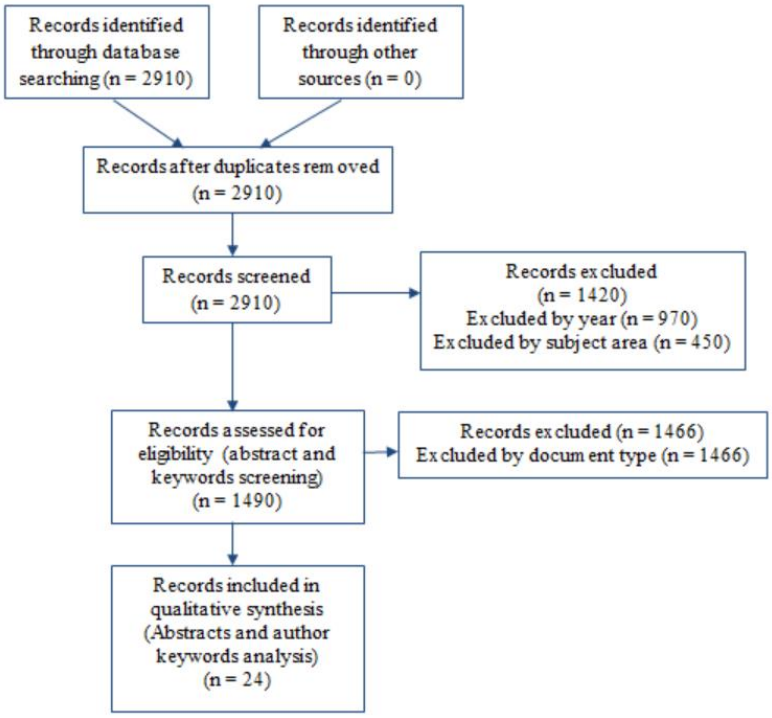
The study population consisted of 2,910 scientific documents initially identified in the Scopus database, related to 3D printing and its application in educational contexts. From this population, a purposive sample was defined through the sequential application of inclusion and exclusion criteria. In the first stage, publications prior to 2020 were excluded, retaining only those published between 2020 and 2025, reducing the corpus to 1,940

records. Subsequently, 450 documents belonging to subject areas not directly linked to the educational field were discarded, including Medicine, Biochemistry, Genetics and Molecular Biology, Dentistry, Agricultural and Biological Sciences, Neuroscience, Nursing, Veterinary, Pharmacology, Toxicology and Pharmaceutics, and Immunology and Microbiology, leaving 1,490 records. Finally, 828 documents were excluded based on publication type; conference proceedings, reviews, conference reviews, errata, editorials, short surveys, retracted articles, and data papers were removed. As a result of this process, a final corpus of 24 documents was constituted, forming the empirical basis for the analysis carried out in the study.

The analysis was conducted at the level of abstracts and author keywords, without reading or analyzing full texts, a methodological decision consistent with the study's objective and the exploratory-interpretive nature of the review. This procedure made it possible to address a broad and systematic corpus, directing the analysis toward identifying thematic patterns, recurrent pedagogical approaches, and prevailing conceptual narratives in the specialized literature. The selection and refinement process of the corpus is summarized through a PRISMA flow diagram (Figure 1). The search equation used is presented below:

> *TITLE-ABS-KEY(("3D printing" OR "additive manufacturing" OR "3D printer" OR "3D technology") AND (education OR teaching OR learning OR classroom OR pedagogy OR "educational use") AND (STEAM OR STEM OR "science education" OR "technology education" OR "engineering education" OR "arts education" OR "mathematics education" OR competencies OR skills))*

**Figure 1**
*PRISMA flow diagram*




*Note.* The qualitative synthesis was conducted at the level of abstracts and author keywords. Full-text analysis was not undertaken, given the scope and objectives of the study.

**Table 1**
*Inclusion and exclusion criteria*

| Criterion | Inclusion | Exclusion |
|---|---|---|
| Publication year | Between 2020 and 2025 | Publications prior to 2020 |
| Subject area | The following areas were included: Engineering, Computer Science, Social Sciences, Materials Science, Mathematics, Physics and Astronomy, Decision Sciences, Chemical Engineering, Business, | The following areas were excluded: Medicine, Biochemistry, Genetics and Molecular Biology, Dentistry, Agricultural and Biological Sciences, Neuroscience, Nursing, Veterinary, Pharmacology, |

| | | |
|---|---|---|
| | Management and Accounting, Energy, Arts and Humanities, Environmental Science, Earth and Planetary Sciences, Chemistry, Psychology, Multidisciplinary, Economics, Econometrics and Finance, Health Professions. | Toxicology and Pharmaceutics, Immunology and Microbiology. |
| Document type | The following documents were included: Article, Book chapter, Book. | The following documents were excluded: Conference paper, Review, Conference review, Erratum, Short survey, Editorial, Retracted, Data paper. |

The information collection technique employed was systematic documentary review, centered on the analysis of abstracts and author keywords from the selected documents, given that these elements condense the objectives, methodological approaches, and main contributions of each study. As a supporting instrument for data production and organization, a documentary analysis matrix was used, constructed from records exported from Scopus, which enabled the systematization of information and facilitated the thematic coding process. The qualitative analysis was developed through an inductive coding process aimed at identifying recurring conceptual patterns, dominant thematic axes, and pedagogical approaches present in the literature, which were subsequently grouped into interpretive categories that enabled a qualitative synthesis of the corpus.

From an ethical standpoint, the study did not involve human participants nor require informed consent, as it relied exclusively on the analysis of publicly accessible secondary sources. Nonetheless, ethical principles associated with the responsible use of scientific information were upheld, including proper citation of sources, respect for intellectual authorship, and faithful presentation of results. Among the main limitations of the study, the reliance on a single database is acknowledged, as well as the analysis restricted to abstracts and keywords, which may limit the interpretive depth of some works. However, these methodological decisions are consistent with the study's objective and allow for a systematic, coherent, and replicable overview of recent research on 3D printing and STEAM education.

## Results

The qualitative analysis of the 24 selected documents made it possible to identify thematic patterns, predominant pedagogical approaches, and discursive trends in the recent scientific literature on the educational use of 3D printing. Based on the systematic review of abstracts and author keywords, the results were organized around three main axes: (1) dominant research themes, (2) educational approaches and associated competencies, and (3) emerging conceptual narratives.

**Dominant research themes on 3D printing in education**

The analysis of the abstracts reveals a strong thematic concentration around additive manufacturing, design, and applied learning processes, particularly in engineering education contexts. 3D printing is recurrently presented as a technology oriented toward prototyping, three-dimensional visualization, and technical problem-solving, which reflects a predominantly instrumental focus.

**Table 2**

*Dominant themes identified in the abstracts*

| Dominant theme | Characterization |
|---|---|
| Additive manufacturing and prototyping | Use of 3D printing as a tool for designing and materializing technical solutions. |
| Design-based learning | Emphasis on iterative design processes as a formative strategy. |
| Engineering education | Predominance of studies developed in technical and engineering programs. |
| Educational technology | Integration of 3D printing as a resource to support teaching-learning processes. |

These results show that, although 3D printing is broadly incorporated into educational contexts, its use remains mostly tied to technical disciplines, with a still-limited presence in other levels and areas of the school curriculum.

**Pedagogical approaches and associated STEAM competencies**

From a pedagogical perspective, the analyzed documents show a clear predominance of active learning approaches, particularly those associated with project-based learning and problem-based learning. In these contexts, 3D printing operates as a mediator that facilitates the practical application of knowledge and the development of technical competencies.

**Table 3**

*Pedagogical approaches and identified STEAM competencies*

| Pedagogical approach | Associated STEAM competencies |
|---|---|
| Active learning | Critical thinking, problem-solving |
| Project-based learning | Design, collaboration, practical application |
| Engineering education | Technical and technological competencies |
| Interdisciplinary STEAM approach | Integration of scientific and technological knowledge |

Nevertheless, the qualitative analysis reveals an asymmetry in the implementation of the STEAM approach, where scientific, technological, and engineering dimensions are more developed, while artistic and creative components remain underrepresented. This finding suggests that the STEAM paradigm is often adopted as a conceptual framework, but does not always translate into balanced curricular integration.

**Discursive trends and conceptualization of 3D printing's role**

The analysis of narratives present in the abstracts and keywords allowed for the identification of different ways of conceptualizing 3D printing in education. A view that conceives it as a technological tool, oriented toward efficiency and the development of technical skills, predominates, although discourses highlighting its potential as a pedagogical resource and strategy for educational innovation are beginning to emerge.

**Table 4**

*Predominant conceptual narratives*

| Narrative | Description |
|---|---|
| 3D printing as a tool | Instrumental view centered on technology and prototyping. |
| 3D printing as a pedagogical resource | Approach oriented toward active and experiential learning. |
| 3D printing as educational innovation | Relationship with curricular modernization and STEAM education. |
| Scarce reference to evaluation | Limited discussion of long-term educational impact. |

These results point to a progressive transition from technocentric approaches toward more pedagogical perspectives. However, the limited presence of studies addressing learning assessment, competency transfer, and long-term impact constitutes a relevant gap in the recent literature.

## Discussion

The findings confirm that recent research on the educational use of 3D printing is strongly influenced by technical and applied approaches, especially within engineering education and related fields. This result is consistent with previous studies indicating that additive manufacturing has been incorporated into education primarily as an extension of industrial and design processes, rather than as a comprehensive pedagogical strategy (Berman, 2012; Simpson et al., 2017; Gebhardt & Hötter, 2016; Ruipérez-Valiente et al., 2020). In this sense, the predominance of narratives centered on prototyping and additive manufacturing reflects an instrumental conception of technology, where emphasis is placed on technical mastery over didactic reflection.

From a pedagogical standpoint, the qualitative analysis shows that 3D printing is recurrently articulated with active learning methodologies, particularly project-based learning and problem-based learning. This finding aligns with the literature highlighting the effectiveness of these methodologies in promoting meaningful learning, especially when integrating technologies that allow for experimentation and the materialization of abstract ideas (Kolodner et al., 2003; Lou et al., 2011; Martín-Gutiérrez et al., 2017). However, although these approaches favor the development of cognitive and technical competencies, the results suggest that their implementation does not always translate into deep pedagogical integration, but rather, in many cases, remains confined to isolated experiences or highly specialized contexts (Ertmer & Ottenbreit-Leftwich, 2010; Redecker & Punie, 2017).

Regarding the STEAM approach, the study's findings show a partial and asymmetric adoption of the paradigm. While scientific, technological, and engineering components are widely represented, artistic and creative dimensions are underrepresented in the analyzed literature. This tendency has been noted by various

authors, who warn that the incorporation of the "A" component in STEAM is often addressed superficially, without genuine curricular integration that fosters creativity, expression, and divergent thinking (Yakman, 2008; Land, 2013; Henriksen, 2017; Quigley & Herro, 2016; Herro & Quigley, 2017). In this context, 3D printing holds significant potential to articulate design, creativity, and technology, although this potential has not yet been fully exploited in the reviewed studies.

Another relevant aspect identified in the discussion is the limited attention that the literature pays to learning assessment and the long-term educational impact of 3D printing. Although numerous studies report improvements in motivation, participation, and conceptual understanding, few investigations systematically analyze competency transfer, sustainability of learning, or their influence on subsequent academic performance (Huang & Lin, 2017; Ngo et al., 2018; Henriksen et al., 2019). This gap reinforces the need to move toward studies incorporating more robust evaluative designs and longitudinal approaches.

From a contextual perspective, the results also allow for the observation of a growing, albeit still limited, presence of studies developed in Latin American contexts. As recent research indicates, the adoption of technologies such as 3D printing in the region is conditioned by structural factors, including access to technological resources, teacher training, and institutional educational policies (Calva-Chávez et al., 2025; Koehler & Mishra, 2013; Dede et al., 2013). Nonetheless, the experiences reported show that when these technologies are integrated in a planned and context-sensitive manner, they can contribute significantly to the development of transversal competencies and pedagogical innovation.

Taken together, the results discussed suggest that research on 3D printing in education is in a transitional phase, gradually moving from a technocentric view toward more pedagogical and interdisciplinary approaches. However, important challenges persist, related to the balanced integration of the STEAM approach, learning assessment, and the expansion of educational contexts in which this technology is implemented. In this scenario, future research should focus on deepening pedagogical design, teacher training, and impact evaluation, with the aim of consolidating the use of 3D printing as a meaningful and sustainable educational strategy (Tranfield et al., 2003; Petticrew & Roberts, 2006; Aria & Cuccurullo, 2017; Selwyn, 2015).

## Conclusions

The analysis allows for the assertion that 3D printing has been incorporated into recent educational literature primarily from a functional and applied logic, which has favored its consolidation as a didactic resource in technical and professional training contexts. Although this orientation has contributed to strengthening active methodologies based on design and problem-solving, it has also conditioned the way in which the technology is pedagogically conceptualized, privileging its instrumental dimension over its comprehensive formative potential.

From this perspective, the study's findings suggest that the STEAM approach has been adopted only partially in the analyzed research, operating more as a declarative framework than as a fully articulated pedagogical model. The limited integration of artistic and creative dimensions does not reflect an absence of potential in 3D printing itself, but rather curricular and methodological decisions that continue to reproduce a fragmented view of interdisciplinary learning. In this regard, the results allow for the affirmation that technology alone does not constitute a transformative factor, but rather that its educational impact depends on the pedagogical design that supports it.

Likewise, the study brings to light a relevant gap in scientific production concerning the systematic evaluation of learning and the measurement of educational impact over the medium and long term. The scarcity of research with robust evaluative designs limits the possibility of more precisely establishing the real reach of 3D printing in the development of STEAM competencies, especially in educational contexts other than higher education in engineering. This limitation does not invalidate the existing contributions, but it does delimit the level of generalizability of their results.

Based on the foregoing, it is considered necessary for future research to deepen the pedagogical analysis of 3D printing, incorporating evaluative approaches, longitudinal designs, and diverse educational contexts, such as K-12 schooling and teacher education. Likewise, it is relevant to advance toward studies that more systematically explore the balanced integration of the different dimensions of the STEAM approach, particularly those linked to creativity, expression, and divergent thinking. In this way, the pending task remains open to the academic community, inviting an expansion and complementation of the findings presented, with the purpose of strengthening an educational integration of 3D printing grounded in solid and contextualized pedagogical evidence.

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