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Integration of Maker Education in STEAM: A Systematic Literature Review

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Abstract

Background/purpose. There is increasing interest in incorporating maker culture into primary and secondary education to foster student competencies beyond academic achievement and prepare students for 21st-century challenges. This systematic literature review examines the implementation of maker education in formal educational contexts, focusing on its benefits for students. The study addresses three objectives: (1) to analyze the terminology used to describe maker-based interventions; (2) to identify the variables, assessment instruments, and results reported; and (3) to synthesize best practices for implementation in formal education.

Materials/methods. Following PRISMA guidelines, 25 articles published between 2013 and 2023 were selected from the Web of Science, Scopus, ERIC, and Dialnet databases.

Results. The most frequently reported outcomes include increases in student motivation, self-efficacy, and socioemotional development. A variety of instruments are used to assess these interventions, though few studies explicitly evaluate content knowledge. “Maker education” is the most used term to describe these practices, although terminology across studies remains diverse. The review also highlights a range of best practices, including collaborative learning, hands-on activities, inclusive materials, pedagogical integration, and formative feedback.

Conclusion. Overall, the findings suggest that maker education has strong potential to enrich STEAM-based, student-centered learning in formal education. By fostering creativity, critical thinking, and active participation, it provides teachers with innovative pedagogical strategies to design meaningful, inclusive, and motivating learning experiences.

1. Introduction

In a world facing increasingly complex problems, the development of sophisticated skills is essential, and such skills can only be cultivated through pedagogical methodologies explicitly designed to address the social challenges of the twenty-first century (Monar-Narajo & Freire-Guevara, 2023). Preparing learners in STEAM fields—Science, Technology, Engineering, Arts and Mathematics—is crucial to respond effectively to the requirements of a digital society (García-Fuentes et al., 2023).

Beyond disciplinary knowledge, the STEAM approach fosters transdisciplinary thinking and problem-solving skills (Madden et al., 2013). However, studies have shown a persistent gap between classroom activities and students' everyday experiences (Nadal & Domínguez, 2023; Rodriguez et al., 2021). To increase student motivation, learning experiences should be relevant and situated in real-life contexts (Rodriguez et al., 2021; Weng et al., 2022). When learners engage with everyday situations, they are more likely to develop open-minded and flexible in identifying new possibilities and opportunities (Forbes et al., 2021; Jia et al., 2021; Litts et al., 2019). Furthermore, engagement in authentic, hands-on STEAM activities can strengthen students' motivation and improve self-efficacy, as they experience success in problem-solving and observe tangible outcomes of their efforts (Santos et al., 2025). Educational innovation entails considering curricular design, employing technological tools, and creating learning environments to prepare students to address future challenges (Shively et al., 2021). Within this framework, the incorporation of maker culture has been increasingly promoted (Carrasco & Bautista, 2023), fostering the proliferation of makerspaces in schools, secondary schools and public spaces (Forbes et al., 2021).

2. Literature Review

The maker movement emphasizes the innovative use of tools, particularly digital technologies (Leonard et al., 2022). It also aims to develop technical skills in digital fabrication through processes such as 3D printing, programming, and electronics (Schlegel et al., 2019). Essentially, it involves hands-on learning through design, fabrication and restoration of objects by combining traditional and modern technologies. While the movement can be traced back to 1980s, it has become widespread and was incorporated into informal educational settings in the early 2000s (Lee et al., 2020a). The creation of the magazine "Make" in 2005 and the first Maker Faire held in California in 2006, promoted by Dale Dougherty, played a pivotal role in disseminating the maker movement within society (Weng et al., 2022). In the field of formal education, Paulo Blikstein was among the first to integrate digital fabrication and maker culture into classrooms by establishing makerspaces in schools—a strategy he regarded as a means of making powerful ideas and creative tools more accessible to students (Blikstein, 2013).

The concept of maker education has been defined in several ways. Fleming (2015) describes it as a process of turning knowledge into action. Lundberg and Rasmussen (2018) argue that the primary goal of maker projects is for learners to create physical objects as an outcome of newly acquired knowledge and skills. One of the most influential definitions is provided by Veldhuis et al. (2021), who describes maker education as "project-based learning through activities focused on designing, building, modifying, and/or repurposing material objects oriented toward making, using either traditional craft techniques or digital technologies, resulting in a product that can be used, interacted with, or demonstrated" (Veldhuis et al., 2021, p.1). These conceptualizations are particularly important because they underline the shift from passive knowledge acquisition to active knowledge construction, which lies at the heart of innovative educational practices. However, the coexistence of multiple definitions also reflects conceptual ambiguity, making it difficult to compare studies and interventions.

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Over the past two decades, maker culture has become increasingly integrated into education (Chu et al., 2017). Makerspaces have been established not only within informal learning environments such as libraries, museums, and community centers, but also within formal educational institutions, including schools and universities (Weng et al., 2022). Research has examined diverse applications. For instance, Mylonas et al. (2019) investigated the use of an IoT lab kit combined with gamification to enhance energy awareness, while Wang et al. (2022) investigated maker-based activities in high school technology courses as a means of fostering creativity.

These examples illustrate the growing adoption of maker education, while simultaneously underscoring persistent challenges. Many interventions report positive outcomes but do not consistently specify how competencies, skills, or attitudes are measured. Variables such as creativity, motivation, and collaboration are frequently assessed using diverse instruments (surveys, observations, self-reports) which limits comparability across studies. This lack of consistency makes it difficult to evaluate the actual impact of maker education. It is therefore essential to clarify which variables and instruments are employed to assess learning processes and outcomes. One rationale for introducing of this approach is providing learners with multiple opportunities to develop their STEAM skills and knowledge (Forbes et al., 2021). The main educational challenge lies in transforming the traditional transmissive model of instruction; teachers are encouraged to transcend the conventional role of delivering isolated subjects (Chu et al., 2017). However, interdisciplinary teaching practices remain relatively uncommon. Moreover, there is growing demand for alternative learning methods that emphasize addressing real-world challenges and problems.

Maker education fosters creativity and provides access to digital and technological tools. The STEAM approach equips learners with the knowledge and skills required to design activities from a transdisciplinary perspective. Therefore, both approaches complement each other, and their application in educational institutions is compatible. Moreover, incorporating the "A" for Arts in the STEM acronym (Perignat & Katz-Buonincontro, 2019) adds further relevance to the combined application of maker education and STEAM. The combination of these disciplines can benefit learners by fostering critical problem-solving skills and related capabilities (Stevenson et al., 2019). Additionally, the identification and design of authentic problems must be carefully considered and validated through appropriate tools (Kafai et al., 2017). In line with this perspective, the study is grounded in the STEAM approach, as it integrates different disciplines and emphasizes creativity, problem-solving, and collaboration.

Beyond conceptual definitions and evaluative frameworks, literature has documented several promising practices associated with maker education. A recurring theme concerns learning through errors. Maker education encourages learners to engage in trial and error, take risks and share experiences as integral components of the learning process (Hughes et al., 2021; Jia et al., 2021;). This perspective contributes to normalizing mistakes and reframing them as opportunities for growth (Rodriguez et al., 2021). However, the extent to which error-driven learning translates into measurable competencies remains unclear, suggesting the need for systematic evaluation of this practice.

Collaboration constitutes another key dimension of maker education. Maker projects often involve groups with diverse knowledge levels, fostering peer learning and communication skills (Forbes et al., 2021; Spieler et al., 2022). Empirical studies have also reported correlations between problem difficulty and learners' social interactions (Martin et al., 2020). Yet, collaborative practices do not always ensure equitable participation, as group dynamics may reproduce inequalities, highlighting the need for educators to deliberately design interventions.

Inclusivity and the democratization of tools are central themes within maker culture. Educational activities should take into account learners' diverse socioeconomic backgrounds, genders, and

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abilities (Martínez et al., 2021; Torralba, 2019). This emphasis aligns with the movement's broader goal of reducing barriers and advancing equity. However, the maker movement has been criticized for being predominantly composed of white males from middle or high socioeconomic backgrounds (Greenberg et al., 2020). Yet, inclusivity is more often presumed than systematically assessed, revealing a persistent gap in the literature.

Finally, maker practices gain greater significance when tasks are authentic and explicitly connected to real-world problems (Kafai et al., 2017; Perignat & Katz-Buonincontro, 2019). Such tasks foster problem-solving and transdisciplinary thinking (Stevenson et al., 2019). However, while these examples highlight the potential of maker education, there remains limited synthesis regarding which strategies prove most effective across diverse contexts.

In recent years, research in maker education has grown substantially, yielding important advances in knowledge and understanding. This growth underscores the importance of reviewing existing work to better delineate its scope and limitations. A systematic literature review (SLR) constitutes a key methodological approach for synthesizing existing knowledge (García-Peñalvo, 2017) by not only summarizing prior studies but also identifying research gaps and opportunities for future inquiry. In the context of maker education, SLRs provide a comprehensive overview of the field's evolution and highlight areas where further research is required.

Over the past decade, several literature reviews have examined the relationship between the maker movement and education. For example, Schad and Jones (2020) examine this connection in broad terms , while Soomro et al. (2023) analyze makerspaces as environments that foster creativity. Another review by Korhonen et al. (2023) addresses the relationship between pedagogy and maker education. Rouse and Rouse (2022) conducted a systematic review, focusing on best practices in makerspaces and the strategies implemented within these interventions. Similarly, Quintana-Ordorika et al. (2024) investigate the incorporation of maker education into teacher training programs. However, they highlight a significant gap in research evaluating whether students acquire knowledge when maker education is implemented in formal educational contexts.

Emerging from the state of the art, there is a clear need to examine the integration of maker education into primary and secondary education. In particular, it is important to analyze the educational interventions implemented to date with a focus on how they assess student development in terms of competencies, skills and acquisition of knowledge and their relationship with the STEAM approach. Given the lack of consensus on the terminology used within educational maker contexts, a focused analysis of the terminology employed to describe these interventions is also warranted.

This study aims to review the implementation of maker culture in the context of primary and secondary education. To this end, a systematic literature review is undertaken. The analysis is guided by the following specific objectives:

- (SO1) To review the terminology used when implementing maker culture in the classroom.
- (SO2) To identify the variables and instruments used to evaluate the interventions and their results.
- (SO3) To identify the best maker practices documented in the literature.

3. Methodology

3.1. Type of study

This systematic literature review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2009) and structured

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following the three review phases defined by Kitchenham (2004): planning, conducting, and reporting.

3.2. Planning phase

During the initial planning phase, the research questions and search strategy were collaboratively established by the research team. To ensure transparency and replicability, the review was designed in accordance with an explicit protocol that included:

- Defined inclusion and exclusion criteria
- A clear database search strategy
- A systematic selection and screening process
- Use of qualitative coding for data synthesis

3.3. Study search strategy

The research focused on publications available in the Web of Science, Scopus, ERIC, and Dialnet databases. Keywords were carefully selected to retrieve studies related to educational interventions in the context of maker education. The search terms included “Maker”, “STEAM”, “STEM”, “education”, “primary education” and “secondary education”, combined using the Boolean operators “OR” and “AND.” The specific search string used was: “Maker” AND (“STEAM” OR “STEM”) AND (“education” OR “primary education” OR “secondary education”). To ensure the relevance and timeliness of the studies reviewed, only publications dated between 2013 and 2023 were considered. The literature search concluded on July 13, 2023, and no additional publications were included after that date.

3.4. Inclusion and Exclusion Criteria

The inclusion and exclusion criteria used to assess the relevance of the retrieved publications are shown in Table 1. Regarding the exclusion criteria applied during the study selection, EC3 (Interventions not in the context of formal education) accounted for the highest percentage of exclusions at 23.56%, as many programs outside of school settings were identified (e.g., maker activities in libraries). EC2 (Interventions not in the context of primary or secondary education) also resulted in a significant exclusion rate of 21.54%, due to the presence of studies involving university or adult education contexts. Both EC4 (Publications dated before 2013) and EC6 (Research focused on pre-service teachers) had an equal exclusion rate of 18.85%. EC5 (Systematic reviews, books, or book chapters) accounted for 15.48% of excluded publications. Finally, EC1 (Publications in languages other than English, Catalan, or Spanish) had the lowest exclusion rate at 1.68%, as most publications were in English.

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Table 1. Exclusion and inclusion criteria

Exclusion criteria	
EC1	The publication is in languages other than English, Catalan or Spanish.
EC2	The study is not situated within the context of primary or secondary education.
EC3	The described intervention does not take place in the context of formal education.
EC4	The publication dates from before 2013.
EC5	The publication is a systematic review, a book or a book chapter.
EC6	The research involves pre-service teachers.
Inclusion criteria	
IC1	The article addresses at least two subjects linked to STEAM.
IC2	The publication describes an intervention involving a maker experience.
IC3	The described intervention includes fieldwork or practical experience.

3.5. Study selection process

The screening process followed the PRISMA guidelines and is summarized in Figure 1. A total of 1,032 publications were identified. After eliminating 243 duplicates, 789 records were retained for title screening. This step led to the exclusion of 437 articles. The remaining 352 abstracts were analyzed, resulting in the selection of 55 full-text articles for complete review. Finally, 25 studies met all inclusion criteria and were subjected to a more detailed analysis using an Excel matrix which compiled information such as year, authors, country of publication, language, educational level, variables analyzed, methodology and main findings. This strategy enhanced the quality of the review by ensuring that the selected studies explicitly implemented the maker philosophy.

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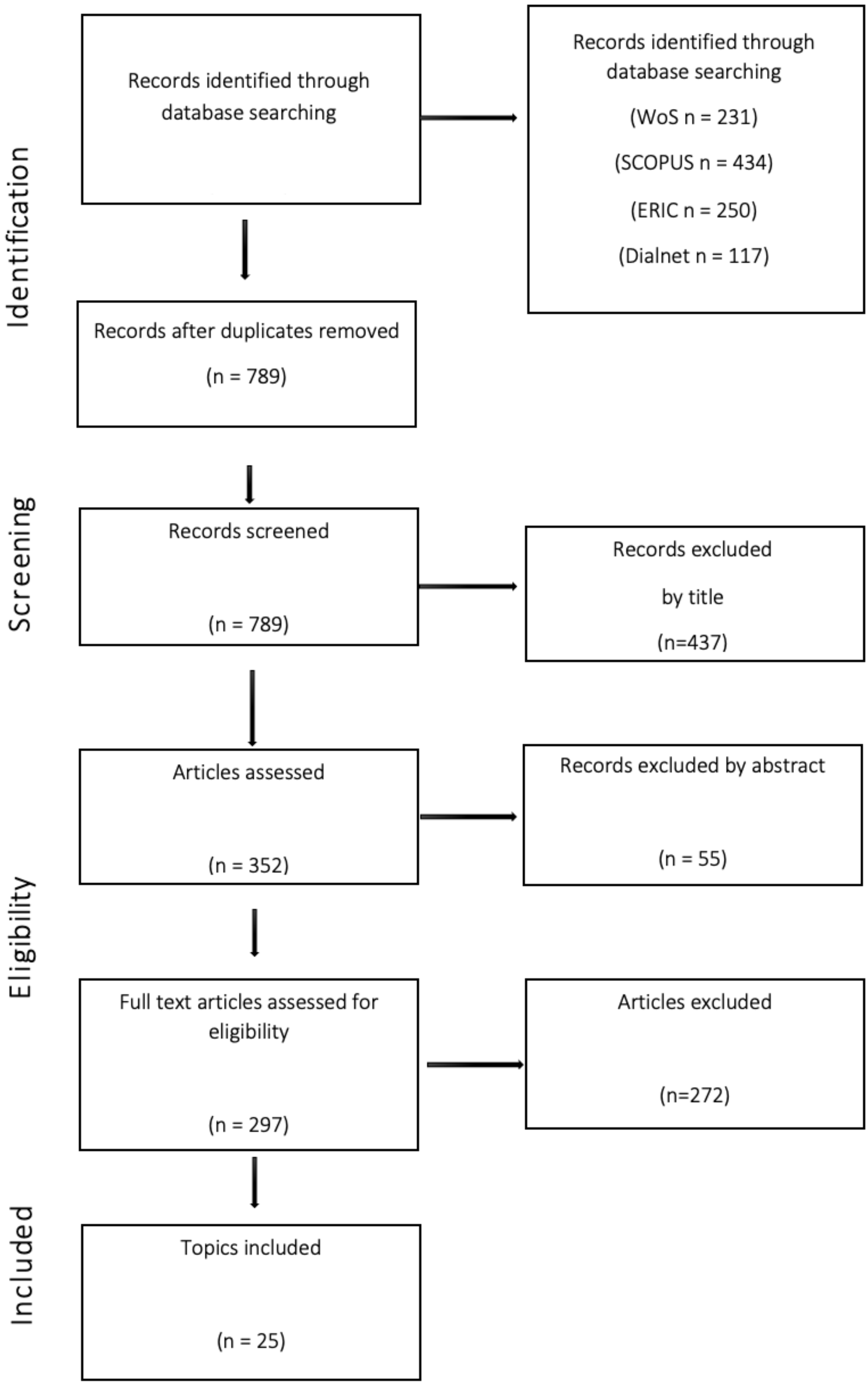

Figure 1. The article selection process follows the PRISMA flow diagram.

4. Results

4.1. Characteristics of Included Studies

The selected articles were mainly situated in the context of primary education (n = 18), with a smaller proportion addressing secondary education (n = 7). With respect to geographical distribution, most publications originated in the Americas, with the United States strongly represented (n = 11). These studies covered diverse locations such as Denver, Pennsylvania, Miami, North Texas and New York City, as well as unspecified regions including the Midwest and parts of Texas or Florida. Canada contributed two studies (both from Ontario), while Brazil was represented by one study from South America. In Asia, four studies were identified—two from Taiwan, one from Hong Kong, and one from Beijing, China—along with one study from India. In Europe, Spain accounted for two studies (both from Barcelona), while Switzerland contributed one (Zurich). Finally, Oceania was represented by two studies from Australia.

With respect to research methodology, the articles were classified as employing quantitative, qualitative, or mixed methods. Despite this methodological diversity, the most common approach was mixed methods (n = 11), which combined quantitative and qualitative analyses. This was followed by quantitative (n = 7) and qualitative (n = 7) approaches, indicating equal representation of these individual methods. Overall, the predominant trend was the adoption of mixed methods for analyzing maker education interventions.

The reviewed interventions varied considerably in duration, spanning from a few hours or days to as long as three academic years. The most frequently reported durations were up to one trimester (n = 6) or up to one month (n = 5). Interventions lasting up to one semester and up to one academic year were also reported with a similar frequency (n = 3 each). Fewer studies reported shorter durations of up to one week (n = 2) or longer durations extending to three academic years (n = 2). Notably, three articles did not specify the duration of the intervention.

Analysis of the STEAM components addressed in the selected interventions revealed a predominance of Science (n = 22) followed by Technology (n = 17) and Mathematics (n = 15). Engineering was also well represented (n = 14), whereas Arts appeared less frequently (n = 11). Although Arts was the least represented component, its inclusion reflects an emerging trend to expand the traditional STEM framework into STEAM by integrating creative and aesthetic dimensions.

4.2. Analysis of terminology

The first specific objective (SO1) focused on reviewing the terminology employed to describe the implementation of maker culture in classroom contexts. Table 2 presents the terminology used across the reviewed articles. The analysis in the fourth column revealed that the term “maker movement” was the most frequently used to describe the origins or foundational aspects of the field. The expression “maker culture” appeared in four instances, as reported by Chu et al. (2017), Hughes et al. (2018, 2021), and Shively et al. (2021). The term “maker-based learning” was less commonly employed, occurring only three times (Forbes et al., 2021; Lee et al., 2020a; Stevenson et al., 2019).

Similar expressions were also identified, as indicated in column 6, such as “Maker STEAM-Based professional learning” (Hughes et al., 2021), “maker-based pedagogies” (Stevenson et al., 2019), or “maker-based experience” (Rodriguez et al., 2021). Torralba (2019) also employs related terminology, as reflected in the same column. In parallel, some authors replaced “based” with “centred,” using expressions such as “maker-centred approach” or “maker approach” (Weng et al., 2022), and “maker-centred philosophy” or “maker-centred instructional practice” (Rodriguez et al., 2021). Although no universally accepted terminology was identified to describe maker interventions, approximately half of the reviewed articles employed the term ‘’maker education’’ to describe the implementation of maker activities in the classroom.

The final column presents additional terminology employed to specify particular aspects of maker interventions. This terminology typically follows a consistent lexical structure, whereby the prefix ''maker'' is attached to a descriptive noun, yielding expressions such as "maker identity", "maker activities", "maker attitudes", "maker materials" and "maker acts", among others. In some instances, authors incorporated STEM or STEAM into the terminology when referring to interventions (Hughes et al., 2021; Jia et al., 2021; Lin et al., 2021; Torralba, 2019; Weng et al., 2022), thereby highlighting the connection between maker practices and interdisciplinary learning frameworks.

Table 2. Analysis of the terminology used in the articles

References	Terminology				
	Maker culture	Maker-based learning	Maker movement	Maker education	Others
(Alekh et al., 2018)			X		Maker skills, maker activities, maker workshops
(Chu et al., 2017)	X		X		Maker classes, maker kits, maker (As a person), maker identity, maker mindset, maker landscape, maker tend, maker activities, maker self-efficacy, maker classrooms
(Fernandez et al., 2020)				X	Maker resources, maker implementation, maker-aligned science
(Forbes et al., 2021b)		X	X		Maker pedagogy, maker activities, maker efficacy, maker attitudes
(Hughes et al., 2018)	X		X	X	Maker-related activities, maker pedagogies, maker tools, maker technologies (Mostly repeated)
(Hughes et al., 2021)	X		X	X	Making STEAM-Based Professional Learning, maker pedagogies, maker approach, maker tools, maker-inspired STEAM teacher professional learning, maker technologies, maker activities, maker lessons, maker resources
(Hwang, 2018)			X		Maker talent
(Jia et al., 2021)				X	STEAM/Maker integrated approach, maker integrated curriculum, maker interest, maker technology, maker approach
(Kafai et al., 2017)					Maker activities, makers (As a person), maker bioengineering, maker tools
(Lee, Arnett, et al., 2020a)				X	maker teachers, maker activities, maker-related content, Teacher-maker coach partnership
(Lee, Samuel, et al., 2020b)		X	X		Maker activities, Maker learning, Maker environment
(Leonard et al., 2022)			X		Maker initiatives, maker activities, Maker experience, maker projects, maker educational designs, maker practices, maker learning, Maker Fair movement, maker acts, maker environment
(Lin et al., 2021)				X	STEAM maker education
(Litts et al., 2019)			X		Maker activities, maker, processes, maker integration, maker approaches, maker ethos, maker environments,

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References	Terminology				
	Maker culture	Maker-based learning	Maker movement	Maker education	Others
(Martin et al., 2020)			X		maker models, maker experiences, maker context, maker studio model, maker artifacts, maker design processes Maker program, team of maker educators, maker mindset, maker curriculum, maker activities, maker group, maker project
(Martínez et al., 2021)			X	X	Maker mindset, maker interventions, maker activities, maker tools, maker education experience, maker projects
(Miller-Ray, 2019)					Maker's guild training program
(Otero & Blikstein, 2016)			X		Maker spaces
(Rodriguez et al., 2021)			X	X	Maker-centered philosophy, maker-centered instructional practices, maker professional development, maker-centered programs, maker mindset, maker-based experience, maker-centered instruction, maker educators, maker activities, maker mentor, maker lessons, maker Community, maker statements, maker ideas, maker products
(Schlegel et al., 2019)			X		Maker mindset, maker identities, maker lesson plan, maker activity, maker self-efficacy
(Shively et al., 2021)	X			X	Maker pedagogy, maker instruction, maker mindset, maker pedagogical practices, maker environment, maker curriculum, maker sustainability
(Spieler et al., 2022a)			X	X	Maker mindset, Maker concepts, Maker principles, Maker fares, Maker community, Maker-Framework
(Stevenson et al., 2019)		X	X		Maker pedagogies, maker materials, maker-based pedagogies, maker units of work, maker activities, maker projects
(Torralba, 2019)			X	X	Maker-Based Integrative STEAM projects, Maker-Based activities, maker-based programs, Maker-Based integrative STEAM curriculum, Maker-based environment, Maker-Based final products
(Weng et al., 2022)			X	X	Maker activities, maker-centered approach, maker approach, maker pedagogy, STEM maker projects, maker learning activities, STEM maker lessons

Instruments, variables, and results related to the maker interventions.

The second specific objective (SO2) focused on reviewing the variables and instruments employed in the selected studies, as well as the results reported from each intervention. The studies meeting these criteria are presented in Table 3, comprising 16 of the 25 interventions included in the systematic review. The remaining nine articles were excluded from the table for the following reasons:

- Two articles did not specify the variables analyzed (Lee et al., 2020a; Lee et al., 2020b).
- Four articles did not report the results of the interventions (Fernandez et al., 2020; Forbes et al., 2021; Rodriguez et al., 2021; Stevenson et al., 2019).
- Two studies did not explicitly identify the instruments used (Hwang, 2018; Litts et al., 2019).
- One article (Shively et al., 2021) did not establish a clear relationship between the variables studied and the outcomes reported.

4.3. Variables analyzed

As shown in Table 3, the second column indicates the number of variables analyzed in each study, ranging from a single variable (Kafai et al., 2017; Spieler et al., 2022) to as many as five (Martin et al., 2020; Martínez et al., 2021). The most frequently analyzed variables were motivation (Alekh et al., 2018; Chu et al., 2017; Jia et al., 2021; Martínez et al., 2021; Schlegel et al., 2019) and interest (Alekh et al., 2018; Chu et al., 2017; Kafai et al., 2017; Martin et al., 2020).

Only a few studies examined student development in terms of knowledge acquisition. For instance, Chu et al. (2017) evaluated academic performance in science, while Torralba (2019) analysed student achievement outcomes. Similarly, Otero and Blikstein (2016) focused on student grades. Few interventions explicitly addressed gender-related aspects. Only three studies directly address this variable (Martínez et al., 2021; Miller-Ray, 2019; Schlegel et al., 2019). However, gender considerations are taken into account during the design, implementation, or evaluation phases in six interventions (Chu et al., 2017; Jia et al., 2021; Martínez et al., 2021; Miller-Ray, 2019; Schlegel et al., 2019), indicating a growing, though still limited, recognition of the need for inclusivity.

These interventions frequently adopted a learner-centered approach, placing emphasis not only on academic outcomes but also on socioemotional dimensions, which are considered in multiple studies (Alekh et al., 2018; Hughes et al., 2018; Lee et al., 2020a; Lee et al., 2020b; Leonard et al., 2022; Martin et al., 2020; Schlegel et al., 2019; Spieler et al., 2022). Less common variables included collaboration (Hughes et al., 2018), connection to real-life contexts (Hughes et al., 2021), creativity (Weng et al., 2022) and student satisfaction (Lin et al., 2021). Notably, in certain cases, a single variable is analysed through multiple subcomponents. For example, Jia et al. (2021) assessed motivation by breaking it down into four categories: attention, relevance, satisfaction, and confidence. Finally, it is important to note that the majority of interventions focused primarily on student development, with very limited attention to teacher growth or professional learning. Only two studies address teacher-related variables (Miller-Ray, 2019; Spieler et al., 2022).

4.4. Instruments analyzed

The third column of Table 3 presents the instruments employed in each study. It is evident that several articles mention data collection processes without clearly specifying the instruments employed (Hughes et al., 2018, 2021; Martínez et al., 2021; Spieler et al., 2022; Torralba, 2019). In some of these cases, descriptions of the instruments were superficial or absent; however, other studies provided explicit details regarding the tools applied (Alekh et al., 2018; Chu et al., 2017; Jia et al., 2021; Leonard et al., 2022; Lin et al., 2021; Miller-Ray, 2019; Schlegel et al., 2019).

Among the most commonly employed tools were instruments related to motivation. For instance, Lin et al. (2021) utilized the Motivated Strategies for Learning Questionnaire (MSLQ), which includes 28 items rated on a five-point Likert scale. The questionnaire is organized into five parts: Learning Strategies, Self-Efficacy, Intrinsic Value, Anxiety and Lack of Learning Strategies. The items

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prompted learners to reflect on their study habits before exams, interest in classroom activities, test-related stress, and attentiveness during lessons.

Similarly, Jia et al. (2021) employed an adapted version of Keller's (2009) ARCS motivation model. The original version comprised 33 items, but the study employed only 17 to suit the participants' age range. These items are distributed across four dimensions: Attention (6 items), Relevance (4), Confidence (4), and Satisfaction (3). Responses were scored on a five-point Likert scale.

In addition to motivation, self-efficacy represented another frequently measured variable. One of the most widely recognized tools for this purpose was the General Self-Efficacy Scale (GSE), which was administered by Alekh et al. (2018). Responses were scored on a scale from 1 to 4 and addressed aspects such as job satisfaction, emotional well-being (e.g., depression, anxiety, stress), and problem-solving ability.

Chu et al. (2017) employed the Self-Perception Profile for Children (SPPC), which consisted of 30 items divided into five categories: Scholastic Competence, Social Competence, Athletic Competence, Physical Appearance and Behavioral Conduct. Learners responded on a five-point Likert scale, providing insight into their perceived performance in class, ease of making friends, physical capabilities and body image.

Finally, Leonard et al. (2022) employed the School Attitude Survey (SAS), a 34-item questionnaire with responses rated on a five-point Likert scale ranging from ''strongly disagree'' to ''strongly agree''. The items explore attitudes toward learning, interest in acquiring new knowledge and perceptions of relationships with teachers, classroom dynamics and the broader school environment.

Beyond quantitative instruments, some studies incorporated interviews as a data collection tool. However, in several cases the interview protocols were not detailed, and no information was provided regarding the specific questions asked (Hughes et al., 2018, 2021; Martin et al., 2020; Otero & Blikstein, 2016; Spieler et al., 2022). Other qualitative methods, such as field notes, were also employed (Hughes et al., 2018, 2021; Kafai et al., 2017) often serving to contextualize observations during the interventions.

To summarize, most studies favoured quantitative instruments, although the presence of qualitative methods was also evident including interviews, classroom observations, and photographic documentation. Overall, there was a clear tendency to combine quantitative and qualitative tools, which aligns with the predominance of mixed-method approaches identified in the review.

4.5. Results from included studies

The fourth column summarizes the results reported in the studies. Several interventions applying maker education through digital and technological tools such as 3D printers and laser cutters reinforced the association between maker practices and the use of such technologies (Leonard et al., 2022; Schlegel et al., 2019). In addition, technological processes such as programming, electronics, prototyping, and the creation of technology-based artefacts were frequently integrated. Most interventions also incorporated interdisciplinary activities, often aimed at fostering creativity, particularly during the design and creation of artefacts.

One of the most consistent findings across studies was an increase in student interest (Alekh et al., 2018; Kafai et al., 2017; Martin et al., 2020; Martínez et al., 2021; Schlegel et al., 2019; Weng et al., 2022). Notably, some studies went beyond measuring general academic interest, focusing instead on interest in STEM fields (Weng et al., 2022), specific school subjects, or even in making activities themselves (Martínez et al., 2021). For example, Alekh et al. (2018) reported increased interest in mathematics, engineering and physics following the intervention. Some studies continued to refer exclusively to STEM rather than STEAM (Martin et al., 2020; Miller-Ray, 2019; Weng et al., 2022).

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Another recurring positive outcome was an increase in student motivation, as reported across several interventions (Alekh et al., 2018; Jia et al., 2021; Lin et al., 2021; Martínez et al., 2021). Notably, none of the studies reported either a decline or stagnation in motivation. A particularly relevant finding from Alekh et al. (2018) was the identification of a relationship between higher motivation and reduced pressure on students, highlighting the positive socioemotional impacts of maker education.

Moreover, an increase in self-efficacy was also a common finding (Chu et al., 2017; Jia et al., 2021; Martin et al., 2020; Martínez et al., 2021). In all cases where self-efficacy was measured, a consistent upward trend was observed, with some interventions reporting statistically significant improvements in this variable (Chu et al., 2017; Martínez et al., 2021; Schlegel et al., 2019). Similarly, another important outcome observed in some interventions was improved knowledge acquisition. Unlike motivation which tends to be uniformly labeled across studies this variable was described using different terminology depending on the authors. For instance, Otero and Blikstein (2016) referred to it as an "increase in student results (grades and performance)," while Jia et al. (2021) described it as variations in STEAM concepts.

Some studies also reported benefits for students with special educational needs. Hughes et al. (2018) observed improvements in leadership skills and overall development among learners with special needs. Likewise, Martin et al. (2020) reported a statistically significant positive effect on autistic students. Other positive results included improved collaboration (Hughes et al., 2018) and a stronger connection between learning and real-life contexts (Hughes et al., 2021).

Although not frequently reported, some studies highlighted increased student creativity (Kafai et al., 2017; Weng et al., 2022) and even enhanced critical thinking (Weng et al., 2022), thereby reinforcing the value of maker education for fostering higher-order thinking skills. Notably, Kafai et al. (2017) found that students reported greater freedom in expressing ideas and a stronger sense of well-being, even when participating in more structured and less creative activities. In summary, the reviewed interventions assess both quantitative variables. A mixed-method approach is often preferred in these cases.

It is also important to consider the aspects that did not demonstrate improvement in the reviewed interventions. Although no consistent negative outcomes were identified across studies, certain elements did not show positive development among students. For instance, two studies found no statistically significant differences in maker identity (Chu et al., 2017; Schlegel et al., 2019). In Chu et al. (2017), a slight increase was noted, and a potential link between stronger maker identity and improved academic performance in science was suggested.

Additionally, some studies reported no significant gender-related differences (Miller-Ray, 2019; Schlegel et al., 2019), and no differences were observed based on socioeconomic status (Miller-Ray, 2019). However, Miller-Ray (2019) reported improved attitudes among female teachers, suggesting a potential indirect gender-related impact. Similarly, Martínez et al. (2021) identified minor differences associated with gender, prior experience, and access to maker tools, although these differences were not substantial.

Table 3. Overview of variables, instruments and results

References	Variables/Attributes	Instruments	Results
(Alekh et al., 2018)	-Interest in several subjects -Motivation -Self-efficacy	-GSE (General Self-Efficacy questionnaire) -Motivation questionnaire	-Increase of interest in maths, engineering, physics. -Increase of motivation
(Chu et al., 2017)	-Interest	-The Self Perception Profile for Children (SPPC)	

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References	Variables/Attributes	Instruments	Results
	-Self-Efficacy -Self-Identity -Academic Performance in Science	-Survey	-Increase of the Academic Performance in Science. -Increase in self-efficacy -No statistical differences in maker identity. -Relation between maker identity and Academic Performance
(Hughes et al., 2018)	-Achievement -Confidence and perseverance -Self-regulation -Collaboration and leadership	-Surveys -Questionnaires -Interviews -Digital video and audio recordings -Observation field notes -Individual and focus group interviews	-Improvement in learners with other abilities -Changes in leaderships -Improvement in collaboration
(Hughes et al., 2021)	-Abilities -Connection to life context	-Pre-surveys for previous experiences -Research field notes -Photo and video recording -Interviews	-Improvement in abilities -More connection to life context
(Jia et al., 2021)	-Motivation -Self-efficacy -STEAM concepts	-Learning motivation scale (Keller 2009) -STEAM test questionnaire	-Increase in acquisition of knowledge -Increase of self-efficacy -Increase of motivation
(Kafai et al., 2017)	-Interest in learners	-Photo documentation -Field notes -Focus groups	-Increase in interest -Improvement expressing ideas and creativity
(Leonard et al., 2022)	-Attitude towards science, technology, engineering and mathematics	-School Attitude Survey (SAS) Kennedy et al. 2016	-Significant improvement in attitude. -Relation between initial attitude and impact.
(Lin et al., 2021)	-Learning motivation -Student satisfaction	-MSLQ (Motivated Strategies for learning) -ASQ (Activity Satisfaction Questionnaire)	-Increase in motivation -Increase in satisfaction
(Martin et al., 2020)	-Self-efficacy -Interest -Outcome expectation -Vicarious experience -Science appreciation	-Audio recorded interviews -STEM Self-Efficacy and Career Interest survey -Classroom observations -Participant interviews	-Increase in self-efficacy -Increase in interest -Positivism in autistic learners
(Martínez et al., 2021)	-Self-efficacy -Gender -Prior experience -Interest -Motivation	-Pre and post questionnaire -Survey	-Boys have more previous experience than girls -Increase in interest -Increase in motivation -Increase in self-efficacy
(Miller-Ray, 2019)	-Confidence toward technology -Teachers' attitudes	-Pre and post questionnaire	-No differences in gender aspects

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References	Variables/Attributes	Instruments	Results
	-Gender aspects	-Stages of Adoption questionnaire -Stages of Adoption of Technology Instrument (Christensen, 1997) -STEM Semantics survey	-No differences in socioeconomic status -Increase of teacher's attitude -Increase of confidence toward technology
(Otero & Blikstein, 2016)	-Teacher Expectations -Student's grades	Teachers Interviews where they ask for changes in student's grades	-Increase in student's results (Grades and performance)
(Schlegel et al., 2019)	-Self-efficacy -Interest -Identification with making and science -Gender	-SPPC self-report questionnaire -Maker Mindset Assessment (Maker Effect Foundation, 2015)	-Increase in self-efficacy -No gender differences -Increase in interest -No differences in maker identity
(Spieler et al., 2022)	-Teacher competences	-Pre and post questionnaire -Interviews	-Improvement in teacher competences
(Torralba, 2019)	-Performance results -Expectations -Abilities	-Pre and post-performance test -Quantitative post assessment	-No changes in performance -Increase in abilities
(Weng et al., 2022)	-STEM identity -STEM Interest -STEM content -Creativity	-Questionnaire	-Significant changes in STEM identity -Significant changes in creativity -Significant changes in STEM interest -Significant changes in critical thinking

4.6. Best practices

The third specific objective (SO3) was to identify best practices in maker education as documented in the literature. Drawing on the results obtained, the following table summarizes best practices for teachers to consider when integrating maker education into the classroom. Table 4 is organized into five categories, representing the most common themes identified across the selected publications.

Table 4. Best practices summary

Categories	Best practices	Authors
Collaboration	-Promote teamwork and collaboration among students to solve problems. -Use digital tools that allow sharing	(Alekh et al., 2018; Fernandez et al., 2020; Hughes et al., 2018, 2021; Jia et al., 2021; Lee, Arnett, et al., 2020; Lee, Samuel, et al., 2020; Litts et al., 2019; Otero & Blikstein, 2016; Rodriguez et al., 2021b; Shively et al., 2021; Spieler et al., 2022; Stevenson et al., 2019; Torralba, 2019; Weng et al., 2022)

Categories	Best practices	Authors
	creations online. -Create spaces where students can share ideas and cooperate.	
Practice	-Integrate practical activities that allow the application of theoretical concepts. - Provide opportunities for experimentation and learning through trial and error.	(Alekh et al., 2018; Chu et al., 2017; Fernandez et al., 2020; Forbes et al., 2021; Hughes et al., 2021; Jia et al., 2021; Kafai et al., 2017; Lee, Samuel, et al., 2020; Leonard et al., n.d.; Litts et al., 2019; Martin et al., 2020; Miller-Ray, 2019; Otero & Blikstein, 2016; Rodriguez et al., 2021; Schlegel et al., 2019; Shively et al., 2021; Stevenson et al., 2019; Torralba, 2019; Weng et al., 2022)
Materials	- Provide recycled and low-cost materials to make new objects. - Provide both manual and technological tools to keep students engaged and up-to-date. - Adapt appropriate materials to the age of the students.	(Alekh et al., 2018; Chu et al., 2017; Fernandez et al., 2020; Forbes et al., 2021; Jia et al., 2021; Kafai et al., 2017; Litts et al., 2019; Martin et al., 2020; Otero & Blikstein, 2016; Schlegel et al., 2019; Shively et al., 2021; Torralba, 2019; Weng et al., 2022)
Pedagogy	-Include maker activities with a pedagogical purpose. -Promote project-based learning to encourage creativity. - Promote critical reflection among students.	(Alekh et al., 2018; Chu et al., 2017; Forbes et al., 2021; Jia et al., 2021; Kafai et al., 2017; Lee, Arnett, et al., 2020; Leonard et al., n.d.; Litts et al., 2019; Martin et al., 2020; Rodriguez et al., 2021; Shively et al., 2021; Spieler et al., 2022; Stevenson et al., 2019; Torralba, 2019; Weng et al., 2022)
Feedback and support	- Provide constructive and specific feedback to help students improve. -Take into account the process during the development of the maker activities and the final creation by the evaluation.	(Alekh et al., 2018; Chu et al., 2017; Fernandez et al., 2020; Forbes et al., 2021; Hughes et al., 2021; Martin et al., 2020; Rodriguez et al., 2021; Spieler et al., 2022; Torralba, 2019; Weng et al., 2022)

4.7. Collaboration

Most of the publications in the sample focused on collaboration among teachers and students. In the study by Rodriguez et al. (2021), teachers confirmed the need for a community to share ideas with other educators and to gain access to new technologies. Encouraging students to work collaboratively was found to support problem-solving. Jia et al. (2021) developed a process through which students solved practical engineering problems. Forbes et al. (2021) implemented activities that enhanced students' problem-solving skills across several phases of the program. Other studies also integrated problem-solving activities (Otero & Blikstein, 2016; Stevenson et al., 2019; Weng et al., 2022b), while Spieler et al. (2022b) focused specifically on cooperativism.

4.8. Practice

An important achievement for teachers was the ability to transform knowledge into practical activities. Chu et al. (2017) offered opportunities to create digital as well as physical artifacts. Several processes were included; for example, Litts et al. (2019) incorporated circuitry, coding and crafting into their implementation. Other interventions (Torralba, 2019) also offered practical activities using common materials and tools such as paper, scissors, adhesives, screws and wood. Furthermore, many authors (Hughes et al., 2021; Jia et al., 2021; Rodriguez et al., 2021) promoted diverse processes of trial and error in their interventions. In particular, in Hughes et al.'s (2021) intervention, the emphasis on permission to fail was a central message.

4.9. Materials

Many authors regarded sustainability and material reusability as key factors. The intervention by Alekh et al. (2018) focused on raising awareness and developing solutions to environmental issues. The results of integrating sustainability into teachers' planning showed that many students became more concerned about the impact of waste on the world, as evidenced by the Kafai et al. (2017) intervention. At the same time, educators were expected to prepare students as 21st-century citizens by fostering a culture of repairing objects rather than purchasing new ones. The main goal was to transform learners into builders rather than consumers (Kafai et al., 2017).

4.10. Pedagogy

The reviewed publications highlight the importance of integrating maker activities into teachers' planning. Rodriguez et al. (2021) implemented a strategy to support project planning and align maker education with instructional objectives. In parallel, several interventions aimed at fostering creativity by connecting students' daily experiences with originality (Alekh et al., 2018; Forbes et al., 2021; Jia et al., 2021; Litts et al., 2019), as in the intervention by Weng et al. (2022), which also incorporated problem-solving activities. Encouraging learners to reflect after maker activities has also proven valuable, as demonstrated in the Kafai et al. (2017) intervention.

4.11. Feedback and support

Finally, the reviewed publications emphasize the role of feedback and support. In Torralba's (2019) intervention, teachers analyzed the learning process at multiple stages. Similarly, Alekh et al. (2018) demonstrated the benefits of providing immediate and continuous feedback, which not only reduced distractions but also increased learner engagement. Forbes et al. (2021) emphasized the importance of delivering feedback constructively and linking it to students' reflective processes.

5. Discussion

This systematic review enables a comparison with previous studies and a reflection on their implications. Although the literature has emphasized the lack of consensus regarding terminology (Hughes et al., 2021; Rodriguez et al., 2021), this review reveals that the most employed term is maker education, followed by a diverse set of expressions that highlight the need for greater conceptual precision. The term maker education, although broad, is both clear and concise, effectively distinguishing these practices from other educational interventions by explicitly situating them within the maker paradigm. The coexistence of multiple terminologies remains evident, a phenomenon previously identified by other scholars as a barrier to consolidating the field (Korhonen et al., 2023; Rouse & Rouse, 2022).

One of the most notable findings is the heterogeneity of variables and outcomes examined in maker education interventions. As highlighted by Quintana-Ordorika et al. (2024), there is a notable lack of rigorous studies investigating whether students genuinely acquire curricular knowledge in formal contexts. This review corroborates this gap: while some studies (Chu et al., 2017; Otero & Blikstein, 2016; Torralba, 2019) report measures of academic performance, the majority concentrate on motivation, self-efficacy, interest, or attitudes rather than on the evaluation of specific curricular content; however, some interventions have not reported significant improvements in academic performance or in the acquisition of curricular content, which limits the generalization of the positive results observed (Otero & Blikstein, 2016; Torralba, 2019). The limited number of interventions that address knowledge development may stem from the inherent complexity of assessing curricular learning, particularly given that each intervention focuses on distinct subject matter, thereby complicating comparisons across studies.

Motivation stands out as one of the most recurrently examined variables in the reviewed studies. This finding aligns with previous reviews (Soomro et al., 2023), which emphasize that maker experiences often generate initial enthusiasm and engagement in learning processes. Yet the challenge lies in demonstrating whether such enthusiasm translates into meaningful, enduring learning outcomes. Another consistent finding is that interventions foster students' self-efficacy, a construct closely associated with active learning and a sense of competence. This observation supports Blikstein's (2013) proposition that maker culture has the potential to promote empowering "learning by doing". Furthermore, studies such as Martin et al. (2020) report specific benefits for neurodivergent students, reinforcing the view that maker education can serve as a pathway toward more inclusive practices, as also suggested by Leonard et al. (2022). Less frequently investigated variables include collaboration, real-life connections, creativity, and student satisfaction. Although these aspects have been less often explored, they underscore the multidimensional potential of maker education beyond academic achievement.

From a methodological standpoint, there is a clear trend toward mixed-methods designs, as recommended for addressing complex educational phenomena (Arteaga et al., 2017; Sampieri, 2018). In the reviewed interventions, quantitative variables enable generalization and measurement of student progress (Arteaga et al., 2017), while qualitative variables offer insights into learning processes and broader contextual factors (Herrera, 2017). For this type of educational intervention, combining both perspectives is particularly valuable. Accordingly, mixed-methods approaches that capture numerical trends alongside emotional or personal experiences are often preferred (Sampieri, 2018). Nonetheless, despite this trend, a lack of standardization in the instruments employed remains evident. While some studies report the use of validated scales, others do not specify the tools applied, which compromises the reliability and replicability of findings. This situation hinders systematic comparisons across studies and underscores the urgent need to develop specific instruments for evaluating the effectiveness of maker education in formal contexts, as also suggested by Lundberg and Rasmussen (2018).

Overall, the findings indicate a positive trend in the development of transversal competencies such as motivation, self-efficacy, and active student engagement. This aligns with Weng et al. (2022) and Jia et al. (2021), who highlight the potential of maker education to connect learning with authentic, real-world contexts. Nevertheless, not all studies confirm that this connection consistently translates into deep or sustained learning, which reinforces the need for more systematic pedagogical designs (Nadal & Domínguez, 2023; Rodriguez et al., 2021). Therefore, while immediate benefits are evident, there remains a pressing need for more rigorous and in-depth research to assess the long-term impact of these interventions in formal educational contexts.

While the inclusion of the "A" in the STEAM acronym has underscored the role of creativity in linking maker education to this framework (Perignat & Katz-Bounincontro, 2019), several

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interventions remain situated within the more traditional STEM paradigm. Moreover, variables related to gender and diversity are only marginally addressed, as Torralba (2019) highlights. Although maker education is often associated with reducing the gender gap (Martínez et al., 2021), only a limited number of interventions explicitly examine gender-related dimensions. In line with Leonard et al. (2022) and Jia et al. (2021), the findings suggest that genuine inclusion requires more than material access; it also demands intentional design, attention to equity and specific teacher training.

This review has identified a set of pedagogical best practices that may guide future implementations, with collaboration among students emerging as a central principle. As emphasized by Forbes et al. (2021) and Spieler et al. (2022), cooperative dynamics not only strengthen social and communication skills but also facilitate collective problem-solving of authentic, real-world challenges. These findings align with those of Jia et al. (2021), who argue that meaningful learning is achieved when connected to everyday contexts, a condition more readily fostered through community-based learning. Moreover, as noted by Rodriguez et al. (2021), collaboration should extend beyond students to include teachers, thereby fostering support networks and enabling the transfer of practices.

Hands-on or experiential learning emerges as a cross-cutting principle across all the interventions analyzed. This approach, aligned with Papert's tradition of constructionism (Blikstein, 2013), recognizes failure as an integral component of the learning process, enabling students to experiment openly and to cultivate both critical and creative thinking. Studies such as Hughes et al. (2021) and Litts et al. (2019) concur that when educators permit trial and error without penalization, they foster a psychologically safe environment conducive to active learning.

Another salient practice involves diversifying and sustainably using materials, encompassing both traditional and digital technologies. In line with Kafai et al. (2017) and Alekh et al. (2018), the most successful experiences are not contingent upon advanced equipment—such as 3D printers—but rather on the creative and accessible mobilization of available resources. This perspective coincides with Torralba (2019), who contends that the maker approach should foster accessibility and the democratization of creative tools.

Equally important is the emphasis on formative feedback, understood as continuous, specific, and oriented toward the learning process. As highlighted by Shively et al. (2021), in maker contexts, valuing the learning process is as important as evaluating the final product. Such feedback plays an active role in fostering student autonomy and self-regulation.

By synthesizing the current body of evidence on maker education, this study offers a coherent overview intended to inform both researchers and educators, thereby guiding the design of future interventions and contributing to the development of evidence-based best practices. Drawing on these findings, a set of final considerations is outlined to synthesize the main contributions and limitations of this review.

6. Conclusion

This systematic review examined the educational effects of implementing maker culture in primary and secondary education. It addresses a gap in the literature by providing a systematic synthesis of how maker education is implemented, highlighting trends in terminology, assessment methods and pedagogical strategies that have until now remained scattered across individual studies. The findings suggest that maker education holds significant potential to enhance student motivation, self-efficacy, and engagement, while also fostering critical thinking and problem-solving skills. Importantly, these benefits are not confined to STEAM disciplines but extend to language and humanities subjects, underscoring their versatility and broader curricular relevance.

Despite the diversity of interventions and the promising outcomes documented, this review underscores several enduring challenges. The most frequently examined learning outcomes relate to

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affective or motivational variables, whereas the impact on curricular knowledge remains insufficiently examined. In numerous cases, the assessment tools employed lack standardization, thereby hindering the comparability of results and the generalizability of findings across contexts.

Moreover, although maker education demonstrates potential to support inclusive practices—particularly when implemented through collaborative, project-based approaches—relatively few studies examine variables such as gender or neurodiversity in sufficient depth, achieving effective inclusion demands intentional instructional design, explicit attention to equity, and targeted teacher training, rather than relying solely on access to materials or tools. For successful implementation in formal education, teacher preparation is identified as a decisive factor. Teachers must be equipped not only with maker-related competencies but also with pedagogical strategies aligned with constructionist learning principles. Strengthening teacher networks and fostering collaborative practices among educators are essential for sustaining innovation and ensuring pedagogical continuity.

Additionally, future research should further explore the potential of maker education, given its documented benefits for students' academic performance and skill development. Its inherent flexibility enables integration across diverse subjects and educational contexts, thereby fostering inclusive, student-centered learning environments. In parallel, it is essential to investigate effective training models and support mechanisms for educators seeking to incorporate maker practices into their teaching. The development of validated instruments and structured frameworks for teacher training will also be crucial for advancing research and guiding implementation in formal education.

Overall, this review's findings offer a clearer understanding of how maker education is implemented in primary and secondary education. The synthesis highlights common patterns in terminology, assessment approaches, and pedagogical practices, while also identifying persistent gaps in the evaluation of curricular knowledge and inclusivity. This overview provides valuable insights for both researchers and educators, guiding future interventions and supporting the development of evidence-based best practices in the field.

7. Suggestion

This study has some limitations. Firstly, the diversity of methodologies and outcome measures across the reviewed studies posed challenges for drawing definitive conclusions or conducting a quantitative synthesis. Secondly, several studies provided insufficient detail regarding their evaluation tools, thereby limiting the comparability and reliability of the results. Thirdly, the review was restricted to studies published in English and Spanish, potentially excluding relevant research published in other languages. Lastly, given the emerging nature of maker education, many studies are exploratory or small-scale, thereby limiting the generalizability of the findings and underscoring the need for more robust, longitudinal research.

Declarations

Author Contributions. O.N.: conceptualization, methodology, original draft preparation, and supervision. M.U.: literature review, data curation, and writing – review and editing. C.V.: methodology, validation, and writing – original draft. C.A.: data analysis, visualization, and writing – review and editing. L.G.: final manuscript review and critical feedback. All authors have read and approved the final version of the article.

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