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Research on K-12 maker education in the early 2020s – a systematic literature review

Sini Davies[1] · **Pirita Seitamaa-Hakkarainen**[1]

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Abstract
This systematic literature review focuses on the research published on K-12 maker education in the early 2020s, providing a current picture of the field. Maker education is a hands-on approach to learning that encourages students to engage in collaborative and innovative activities, using a combination of traditional design and fabrication tools and digital technologies to explore real-life phenomena and create tangible artifacts. The review examines the included studies from three perspectives: characteristics, research interests and findings, previous research gaps filled, and further research gaps identified. The review concludes by discussing the overall picture of the research on maker education in the early 2020s and suggesting directions for further studies. Overall, this review provides a valuable resource for researchers, educators, and policymakers to understand the current state of K-12 maker education research.

Keywords Maker education · K-12 education · Systematic literature review · Maker-centered learning · Maker culture · Design and making

Introduction

Maker culture developed through the pioneering efforts of Papert (1980) and his followers, such as Blikstein (2013), Kafai and Peppler (2011), and Resnick (2017). It has gained popularity worldwide as an educational approach to encourage student engagement in learning science, technology, engineering, arts, and mathematics (STEAM) (Martin, 2015; Papavlasopoulou et al., 2017; Vossoughi & Bevan, 2014). Maker education involves engaging students to collaborate and innovate together by turning their ideas into tangible creations through the use of conceptual ideas (whether spoken or written), visual representations such as drawings and sketches, and material objects like prototypes and models (Kangas et al.,

✉ Sini Davies
sini.davies@helsinki.fi

Pirita Seitamaa-Hakkarainen
pirita.seitamaa-hakkarainen@helsinki.fi

[1] Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland

2013; Koh et al., 2015). Another core aspect of maker education is combining traditional design and fabrication tools and methods with digital technologies, such as 3D CAD and 3D printing, electronics, robotics, and programming, which enables students to create multifaceted artifacts and hybrid solutions to their design problems that include both digital and virtual features (e.g., Blikstein, 2013; Davies et al., 2023; Riikonen, Seitamaa-Hakkarainen, et al., 2020). The educational value of such multi-dimensional, concrete making has become widely recognized (e.g., Blikstein, 2013; Kafai, 1996; Kafai et al., 2014; Martin, 2015).

Maker education has been studied intensively, as indicated by several previous literature reviews (Iivari et al., 2016; Lin et al., 2020; Papavlasopoulou et al., 2017; Rouse & Rouse, 2022; Schad & Jones, 2020; Vossoughi & Bevan, 2014; Yulis San Juan & Murai, 2022). These reviews have revealed how the field has been evolving and provided a valuable overall picture of the research on maker education before the 2020s, including only a few studies published in 2020 or 2021. However, the early years of the 2020s have been an extraordinary period in time in many ways. The world was hit by the COVID-19 pandemic, followed by the global economic crises, increasing geopolitical tensions, and wars that have had a major impact on societies, education, our everyday lives, and inevitably on academic research as well. Furthermore, 2023 was a landmark year in the development of artificial intelligence (AI). In late 2022, OpenAI announced the release of ChatGPT 3.5, a major update to their large language model that is able to generate human-like text. Since then, sophisticated AI systems have rushed into our lives at an accelerating speed and are now becoming integrated with other technologies and applications, shaping how we live, work, our cultures, and our environments irreversibly (see, e.g., World Economic Forum, 2023). Thus, it can be argued that towards the end of 2023, the world had transitioned into the era of AI. It is essential that researchers, educators, and policymakers have a fresh overall understanding and a current picture of research on K-12 maker education to develop new, research-based approaches to technology and design education in the present rapidly evolving technological landscape of AI. This is especially important in order to avoid falling back towards shallow epistemic and educational practices of repetition and reproduction. The present systematic review was conducted to provide a 'big picture' of the research on K-12 maker education published in the extraordinary times of the early 2020s and to act as a landmark between the research on the field before and after the transition to the AI era. The review was driven by one main research question: *How has the research on maker education developed in the early 2020s?* To answer this question, three specific research questions were set:

1. What were the characteristics of the studies in terms of geographical regions, quantity of publications, research settings, and research methods?.
2. What were the research interests and findings of the reviewed studies?.
3. How did the reviewed studies fulfill the research gaps identified in previous literature reviews, and what further research gaps they identified?.

The following will outline the theoretical background of the systematic literature review by examining previous literature reviews on maker culture and maker education. This will be followed by an explanation of the methodologies used and findings. Finally, the review will conclude by discussing the overall picture of the research on maker education in the early 2020s and suggesting directions for further studies.

Previous literature reviews on maker culture and maker education

Several literature reviews have been conducted on maker education over the past ten years. The first one by Vossoughi and Bevan (2014) concentrated on the impact of tinkering and making on children's learning, design principles and pedagogical approaches in maker programs, and specific tensions and possibilities within the maker movement for equity-oriented teaching and learning. They approached the maker movement in the context of out-of-school time STEM from three perspectives: (1) entrepreneurship and community creativity, (2) STEM pipeline and workforce development, and (3) inquiry-based education. At the time of their review, the research on maker education was just emerging, and therefore, their review included only a few studies. The review findings highlighted how STEM practices were developed through tinkering and striving for equity and intellectual safety (Vossoughi & Bevan, 2014). Furthermore, they also revealed how making activities support new ways of learning and collaboration in STEM. Their findings also pointed out some tensions and gaps in the literature, especially regarding a focus that is too narrow on STEM, tools, and techniques, as well as a lack of maker projects conducted within early childhood education or families.

In subsequent literature reviews (Iivari et al., 2016; Lin et al., 2020; Papavlasopoulou et al., 2017; Rouse & Rouse, 2022; Schad & Jones, 2020; Yulis San Juan & Murai, 2022), the interests of the reviews were expanded. Iivari and colleagues (2016) reviewed the potential of digital fabrication and making for empowering children and helping them see themselves as future digital innovators. They analyzed the studies based on five conditions: conditions for convergence, entry, social support, competence, and reflection, which were initially developed to help with project planning (Chawla & Heft, 2002). Their findings revealed that most of the studies included in their review emphasized the conditions for convergence, entry, and competence. However, only a few studies addressed the conditions for social support and reflection (Iivari et al., 2016). The reviewed studies emphasized children's own interests and their voluntary participation in the projects. Furthermore, the studies highlighted projects leading to both material and learning-related outcomes and the development of children's competencies in decision-making, design, engineering, technology, and innovation through projects.

Papavlasopoulou and colleagues (2017) took a broader scope on their systematic literature review, characterizing the overall development and stage of research on maker education through analyzing research settings, interests, and methods, synthesizing findings, and identifying research gaps. They were specifically interested in the technology used, subject areas that implement making activities, and evaluation methods of making instruction across all levels of education and in both formal and informal settings. Their data comprised 43 peer-reviewed empirical studies on maker-centered teaching and learning with children in their sample, providing participants with any making experience. In Papavlasopoulou and colleagues' (2017) review, the included studies were published between 2011 and November 2015 as journal articles, conference papers, or book chapters. Most of the studies were conducted with fewer than 50 participants ($n=34$), the most prominent age group being children from the beginning of primary school up to 14 years old ($n=22$). The analyzed studies usually utilized more than one data collection method, mainly focusing on qualitative ($n=22$) or mixed method ($n=11$) approaches. Most included studies focused on programming skills and computational thinking ($n=32$) or STEM subjects ($n=6$). The studies

reported a wide range of positive effects of maker education on learning, the development of participants' self-efficacy, perceptions, and engagement (Papavlasopoulou et al., 2017). There were hardly any studies reporting adverse effects.

Schad and Jones (2020) focused their literature review on empirical studies of the maker movement's impacts on formal K12 educational environments, published between 2000 and 2018. Their Boolean search (maker movement AND education) to three major academic research databases resulted in 599 studies, of which 20 were included in the review. Fourteen of these studies focused on K12 students, and six on K12 teachers. All but three of the studies were published between 2014 and 2018. Similarly to the studies reported in the previous literature reviews (Iivari et al., 2016; Papavlasopoulou et al., 2017; Vossoughi & Bevan, 2014), the vast majority of the studies were qualitative studies that reported positive opportunities for maker-centered approaches in STEM learning and promotion of excitement and motivation. On the other hand, the studies on K12 in- and preservice teacher education mainly focused on the importance of offering opportunities for teachers to engage in making activities. Both, studies focused on students or teachers, promoting equity and offering equally motivating learning experiences regardless of participants' gender or background was emphasized.

Lin and colleagues' (2020) review focused on the assessment of maker-centered learning activities. After applying inclusion and exclusion criteria, their review consisted of 60 peer-reviewed empirical studies on making activities that included making tangible artifacts and assessments to measure learning outcomes. The studies were published between 2006 and 2019. Lin and colleagues (2020) also focused on all age groups and activities in both formal and informal settings. Most studies included applied STEM as their main subject domain and utilized a technology-based platform, such as LilyPad Arduino microcontroller, Scratch, or laser cutting. The results of the review revealed that in most studies, learning outcomes were usually measured through the assessment of artifacts, tests, surveys, interviews, and observations. The learning outcomes measured were most often cognitive skills on STEM-related content knowledge or students' feelings and attitudes towards STEM or computing.

The two latest systematic reviews, published in 2022, also focused on specific research interests in maker education (Rouse & Rouse, 2022; Yulis San Juan & Murai, 2022). Rouse and Rouse (2022) reviewed studies that specifically investigated learning in preK-12 maker education in formal school-based settings. Their analysis included 22 papers from seven countries, all but two published between 2017 and 2019. Only two of the studies focused on early childhood education, and three involved participants from the elementary level. Like previous reviews, most studies were conducted with qualitative methods ($n=17$). On the other hand, in contrast to the earlier reviews (Lin et al., 2020; Papavlasopoulou et al., 2017; Schad & Jones, 2020), the studies included in the review did not concentrate on content-related outcomes on STEM or computing. Instead, a wide range of learning outcomes was investigated, such as 21st-century skills, agency, and materialized knowledge. On the other hand, they found that equity and inclusivity were not ubiquitously considered when researchers design makerspace interventions. Yulis San Juan and Murai's (2022) literature review focused on frustration in maker-centered learning activities. Their analysis consisted of 28 studies published between 2013 and 2021. Their findings of the studies identified six factors that are most often recognized as the causes of frustration in makerspace activities: 'unfamiliar pedagogical approach, time constraints, collaboration, outcome expecta-

tions, lack of skills and knowledge, and tool affordances and availability' (Yulis San Juan & Murai, 2022, p. 4).

From these previous literature reviews, five significant research gaps emerged that required further investigation and attention:

1. Teacher training, pedagogies, and orchestration of learning activities in maker education (Papavlasopoulou et al., 2017; Rouse & Rouse, 2022; Schad & Jones, 2020; Vossoughi & Bevan, 2014).
2. Wide variety of learning outcomes that potentially emerge from making activities, as well as the development of assessment methods and especially systematic ways to measure student learning (Lin et al., 2020; Rouse & Rouse, 2022; Schad & Jones, 2020).
3. Equity and inclusivity in maker education (Rouse & Rouse, 2022; Vossoughi & Bevan, 2014).
4. Practices, tools, and technologies used in makerspaces and digital fabrication (Iivari et al., 2016; Papavlasopoulou et al., 2017).
5. Implementation and effects of maker education in formal, school-based settings and specific age groups, especially early childhood education (Papavlasopoulou et al., 2017; Rouse & Rouse, 2022).

Methodology

This review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, adapting it to educational settings where studies are conducted with qualitative, quantitative, and mixed methods (Page et al., 2021; Tong et al., 2012). Review protocols were defined for data collection, inclusion, exclusion, and quality criteria and the data analysis. In the following, the method used for each stage of the review process will be defined in detail.

Data collection

To gather high-quality and comprehensive data, a search for peer-reviewed articles was conducted in three international online bibliographic databases: Scopus, Education Resources Information Center (ERIC), and Academic Search Complete (EBSCO). Scopus and EBSCO are extensive multi-disciplinary databases for research literature, covering research published in over 200 disciplines, including education, from over 6000 publishers. ERIC concentrates exclusively on educational-related literature, covering publications from over 1900 full-text journals. These three databases were considered to offer a broad scope to capture comprehensive new literature on K-12 maker education. The search aimed to capture peer-reviewed literature on maker education and related processes conducted in both formal and informal K-12 educational settings. The search was limited to articles published in English between 2020 and 2023. Major search terms and their variations were identified to conduct the search, and a Boolean search string was formed from them. The search was implemented in October 2023 with the following search string that was used to search on titles, abstracts, and keywords:

("maker education" OR "maker pedagogy" OR "maker-centered learning" OR "maker centered learning" OR "maker-centred learning" OR "maker centred learning" OR "maker learning" OR "maker space" OR makerspace* OR "maker culture" OR "design learning" OR "maker practices" OR "collaborative invention*" OR co-invention*) AND ("knowledge-creation" OR "knowledge creation" OR "knowledgecreation" OR maker* OR epistemic OR "technology education" OR "design-based learning" OR "design based learning" OR "designbased learning" OR "design learning" OR "design thinking" OR "codesign" OR "co-design" OR "co design" OR craft* OR tinker* OR "collaborative learning" OR inquiry* OR "STEAM" OR "project-based learning" OR "project based learning" OR "project-based learning" OR "learning project*" OR "knowledge building" OR "making" OR creati* OR innovat* OR process*) AND (school* OR pedago* OR "secondary education" OR "pre-primary education" OR "primary education" OR "special education" OR "early childhood education" OR "elementary education" OR primary-age* OR elementary-age* OR "k-12" OR "youth" OR teen* OR adolescen* OR child* OR "tween").*

Inclusion and exclusion criteria

The search provided 700 articles in total, 335 from Scopus, 345 from EBSCO, and 20 from ERIC that were aggregated to Rayyan (Ouzzani et al., 2016), a web and mobile app for systematic reviews, for further processing and analysis. After eliminating duplicates, 513 studies remained. At the next stage, the titles and abstracts of these studies were screened independently by two researchers to identify papers within the scope of this review. Any conference papers, posters, work-in-progress studies, non-peer-reviewed papers, review articles, and papers focusing on teacher education or teachers' professional development were excluded from the review. To be included, the study had to meet all the following four inclusion criteria. It had to:

1. show empirical evidence.
2. describe any making experience or testing process conducted by the participants.
3. include participants from the K-12 age group in their sample.
4. have an educational purpose.

For example, studies that relied purely on statistical data collected outside a maker educational setting or studies that described a maker space design process but did not include any research data from an actual making experience conducted by participants from the K-12 age group were excluded. Studies conducted both in formal and informal settings were included in the review. Also, papers were included regardless of whether they were conducted using qualitative, quantitative, or mixed methods. After the independent screening process, the results were combined, and any conflicting assessments were discussed and settled. Finally, 149 studies were included to be retrieved for further evaluation of eligibility, of which five studies were not available for retrieval. Thus, the screening resulted in 144 included studies with full text retrieved to apply quality criteria and further analysis.

Quality criteria

The quality of each of the remaining 144 studies was assessed against the Critical Appraisal Skills Programme's (2023) qualitative study checklist, which was slightly adjusted for the context of this review. The checklist consisted of ten questions that each address one quality criterion:

1. Was there a clear statement of the aims of the research?.
2. Are the methodologies used appropriate?.
3. Was the research design appropriate to address the research aims?.
4. Was the recruitment strategy appropriate to the aims of the research?.
5. Was the data collected in a way that addressed the research issue?.
6. Has the relationship between the researcher and participants been adequately considered?.
7. Have ethical issues been taken into consideration?.
8. Was the data analysis sufficiently rigorous?.
9. Is there a clear statement of findings?.
10. How valuable is the research?.

The first author assessed the quality by reading each study's full text. To be included in the final analysis, the study had to meet both the inclusion-exclusion and the quality criteria. In this phase, the final assessment for eligibility, 50 studies were excluded due to not meeting the initial inclusion and exclusion criteria, and 32 studies for not filling the criteria for quality. A total of 62 studies were included in the final analysis of this literature review. The PRISMA flow chart (Haddaway et al., 2022; see also Page et al., 2021) of the study selection process is presented in Fig. 1.

Qualitative content analysis of the reviewed studies

The analysis of the studies included in the review was conducted through careful reading of the full texts of the articles by the first author. To answer the first research question: What were the characteristics of the studies in terms of geographical regions, quantity of publications, research settings, and methods; a deductive coding framework was applied that consisted of characterizing factors of the study, its research setting as well as data collection and analysis methods applied. The predetermined categories of the study characteristics and the codes associated with each category are presented in Table 1. The educational level of the participants was determined by following The International Standard Classification of Education (ISCED) (UNESCO Institute for Statistics, 2012). Educational level was chosen instead of an age group as a coding category because, during the first abstract and title screening of the articles, it became evident that the studies describe their participants more often by their educational level than age. The educational levels were converted from national educational systems following the ISCED diagrams (UNESCO Institute for Statistics, 2021).

In addition to the deductive coding, the following analysis categories were gathered from the articles through inductive analysis: journal, duration of the project, number of participants, types of research data collected, and specific data analysis methods. Furthermore,

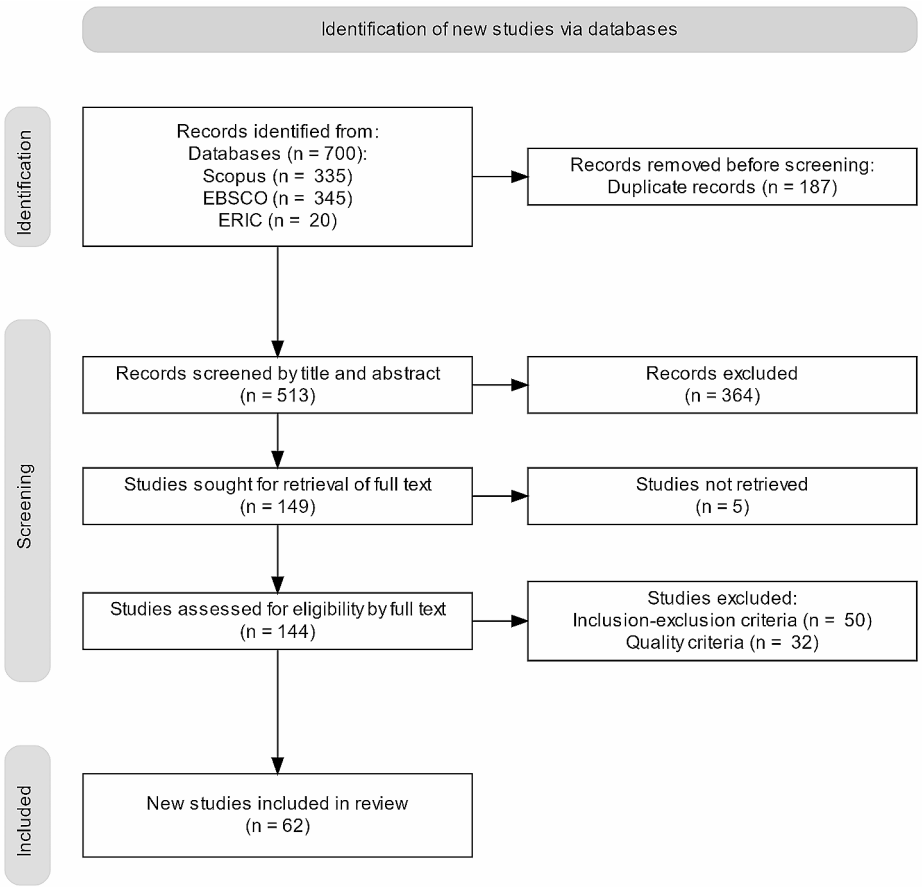


Fig. 1 PRISMA study selection flow chart (Haddaway et al., 2022)

Table 1 Predetermined coding framework of the studies included in the review

Category	Codes applied
Year of publication	Year of publication
Country	The country where the project was conducted in
Formal or informal setting	Formal, informal
Education level	Early childhood, primary, lower secondary, upper secondary
Project type	Digital artifact, material artifact, integrated system, digital exploration
Learning environment	School/classroom, designated makerspace or laboratory, youth or afterschool club, library or museum, summer camp, online
Individual or collaborative task	Individual, collaborative, both
Materials and tools used in the project	Material, digital, both
Method	Qualitative, quantitative, mixed method

the following characteristics of the studies were marked in the data when applicable: if the research was conducted as a case study, usage of control groups, specific focus on minority groups, gifted students, special needs students, or inclusion. Inductive coding and thematic analysis were applied to answer the second research question: what were the research interests and findings of the reviewed studies? The categorization of research interests was then combined with some aspects of the first part of the analysis to reveal further interesting characteristics about the latest developments in the research in maker education.

Findings

In the following, the findings of this systematic literature review will be presented for each research question separately.

Characteristics of research in K-12 maker education in the 2020s

Of the studies included in the review, presented in Table 2 and 20 studies were published in 2020, 17 in 2021, 12 in 2022, and 13 in 2023. The slight decline in publications does not necessarily indicate a decline in interest towards maker education but is more likely due to the COVID-19 pandemic that heavily limited hands-on activities and in situ data collection. Compared to the latest wide-scope review on maker education (Papavlasopoulou et al., 2017), the number of high-quality studies published yearly appears to be at similar levels to those in the previous reviews. The studies included in the present review were published in 34 different peer-reviewed academic journals, of which 13 published two or more articles.

Regarding the geographic distribution of studies conducted on maker education, the field seems to be becoming more internationally spread. In 2020, the studies mainly published research conducted in either the USA ($n=6$) or Finland ($n=12$), whereas in the subsequent years, the studies were distributed more evenly around the world. However, North America and Scandinavia remained the epicenters of research on maker education, conducting over half of the studies published each year.

Most of the reviewed studies used qualitative methods ($n=42$). Mixed methods were utilized in 13 studies, and quantitative methods in seven. Forty-four studies were described as case studies by their authors, and, on the other hand, a control group was used in four quantitative and two mixed methods studies. The analysis indicated an interesting research shift towards making activities part of formal educational settings instead of informal, extracurricular activities. Of the studies included in this review, 82% ($n=51$) were conducted exclusively in formal educational settings. This contrasts significantly with the previous literature review by Papavlasopoulou and colleagues (2017), where most studies were conducted in informal settings. Furthermore, Schad and Jones (2020) identified only 20 studies between 2000 and 2018 conducted in formal educational settings in K12-education, and Rouse and Rouse (2022) identified 22 studies in similar settings from 2014 to early 2020. In these reviews, nearly all studies done in formal educational settings were published in the last years of the 2010 decade. Thus, this finding suggests that the change in learning settings started to emerge in the latter half of the 2010s, and in the 2020s, maker education in formal settings has become the prominent focus of research. The need for further research

Table 2 Studies reviewed. Annotations: countries annotated according to ISO 3166-2 standard (International Organization for Standardization, 2020); formal (F); informal (I); student(s) (S); teacher(s) (T); qualitative (QUAL); quantitative (QUAN); mixed (MIX)

Authors and year	Country	F/I	Age group /education level	Participants	Method
Andersen et al. (2022)	NO	F	Lower secondary	6 S groups	QUAL
Davies et al. (2023)	FI	F	Lower secondary	10 S	QUAL
Doss and Bloom (2023)	US	I	Primary	62 S	MIX
Dúo-Terrón et al. (2022)	ES	F	Primary	142 S	QUAN
Falloon et al. (2022)	AU	F	Primary	500 S	MIX
Fields et al. (2021)	US	F	Upper secondary	248 S+15 T	MIX
Fleer (2022)	AU	F	Early childhood	13 S+2 T	QUAL
Forbes et al. (2021)	AU	F	Early childhood and primary	576 S+24 T	QUAL
Friend and Mills (2021)	AU	I	Primary	116 S	QUAL
Giusti and Bombieri (2020)	IT	F	Primary	4 S	QUAL
Greenberg et al. (2020)	US	I	Lower secondary	12 S	QUAL
Hachey et al. (2022)	US	F	Early childhood	19 S	QUAL
Hagerman et al. (2022)	CA	F	Primary	3 S	QUAL
Hartikainen et al. (2023)	FI	F	Lower secondary	27 S+2 T	QUAL
Herro et al. (2021a)	US	F	Primary	52 S	QUAL
Herro et al. (2021b)	US	F	Lower secondary	52 S	QUAL
Hsu et al. (2022)	US	F	Lower secondary	5 S	MIX
Impedovo and Cederqvist (2023)	IT	F	Primary	1 S	QUAL
Iwata et al. (2020)	FI	F	Lower secondary	41 S+5 T	MIX
Kajamaa and Kumpulainen (2020)	FI	F	Primary	8 S	QUAL
Kajamaa et al. (2020)	FI	F	Primary	94 S+5 T	QUAL
Keune et al. (2022)	US	F&I	Primary	22 S	QUAL
Kumpulainen & Kajamaa (2020)	FI	F	Primary	11 S	QUAL
Kumpulainen et al. (2020)	FI	F	Primary	94 S	QUAL
Lee (2021)	US	I	Lower secondary	4 S	MIX
Leskinen et al. (2023)	FI	F	Primary	20 S	QUAL
Leskinen et al. (2021)	FI	F	Primary	124 S+11 T	QUAL
Li (2021)	US	I	Lower secondary	21 S	QUAL
Lindberg et al. (2020)	US	F	Upper secondary	21 S	QUAL
Liu and Li (2023)	CN	F	Primary	72 S	QUAN
Martin et al. (2020)	US	F	Lower secondary	99 S	MIX
Mehto et al., (2020a)	FI	F	Lower secondary	4 S	QUAL
Mehto et al., (2020b)	FI	F	Lower secondary	3 S	QUAL
Morado et al. (2021)	CR	I	Primary	2 S	QUAL
Mørch et al. (2023)	NO	F	Lower secondary	19 S	QUAL
Ng et al. (2023)	HK	F	Lower secondary	35 S	MIX
Nguyen et al. (2023)	TW	I	Lower secondary	167 S	QUAN
Nikou (2023)	GB	F	Primary	15 S	MIX
Pitkänen et al. (2020)	FI	F	Lower secondary	41 S+5 T	QUAL
Riikonen, Kangas, et al. (2020)	FI	F	Lower secondary	106 S+5T	QUAL
Riikonen, Seitamaa-Hakkarainen, et al. (2020)	FI	F	Lower secondary	26 S	QUAL
Sinervo et al. (2021)	FI	F	Primary	42 S	QUAL
Skåland et al. (2020)	NO	F&I	Primary	3 S	QUAL

Table 2 (continued)

Authors and year	Country	F/I	Age group /education level	Participants	Method
Sormunen et al. (2020)	FI	F	Primary	44 S+4 T	QUAL
Stewart et al. (2023)	US	F	Lower secondary	78 S	MIX
Stornaiuolo (2020)	US	F	Lower secondary	31 S	QUAL
Tan et al. (2021)	SG	I	Lower secondary	4 S+1 T	QUAL
Tenhovirta et al. (2022)	FI	F	Lower secondary	15 S	QUAL
Timotheou and Ioannou (2021)	CY	F	Primary	18 S	MIX
Tisza and Markopoulos (2021)	NL	F	Primary	86 S	QUAN
Tofel-Grehl et al. (2021)	US	F	Upper secondary	85 S+1 T	QUAL
Vongkulluksn et al. (2021)	US	F	Primary	110 S	QUAN
Vuopala et al. (2020)	FI	F	Primary	18 S	MIX
Walan (2021)	SE	I	Primary	10 S	QUAL
Walan and Brink (2023)	SE	F	Lower secondary	65 S+4 T	QUAL
Wargo (2021)	US	I	Primary	2 S	QUAL
Weng et al. (2022a)	HK	F	Lower secondary	95 S	QUAN
Weng et al. (2022b)	HK	F	Lower secondary	70 S	QUAL
Winters et al. (2022)	CA	F	Primary	45 S	QUAL
Xiang et al. (2023)	CN	F	Early childhood	407 S+24 T	MIX
Yin et al. (2020)	US	I	Lower secondary	35 S	QUAN

in formal settings was one of the main research gaps identified in previous literature reviews (Papavlasopoulou et al., 2017; Rouse & Rouse, 2022).

In addition to the shift from informal to formal educational settings, the projects studied in the reviewed articles were conducted nearly as often in school and classroom environments ($n=26$) as in designated makerspaces ($n=28$). Only seven of the studied projects took place in other locations, such as youth clubs, libraries, or summer camps. One project was conducted entirely in an online learning environment. Most of the studied projects involved children exclusively from primary ($n=27$) or lower secondary ($n=26$) education levels. Only three studies were done with students in upper secondary education. Like the previous literature reviews, only a few studies concentrated on children in early childhood education (Papavlasopoulou et al., 2017; Rouse & Rouse, 2022). Three articles reported projects conducted exclusively on early childhood education age groups, and three studies had participants from early childhood education together with children from primary ($n=2$) or lower secondary education ($n=1$).

The number of child participants in the studies varied between 1 and 576, and 14 studies also included teachers or other adults in their sample. The number of participating children in relation to the methods used is presented in Fig. 2. Most of the qualitative studies had less than 100 children in their sample. However, there were three qualitative studies with 100 to 199 child participants (Friend & Mills, 2021; Leskinen et al., 2021; Riikonen, Kangas, et al., 2020) and one study with 576 participating children (Forbes et al., 2021). Studies utilizing mixed methods were either conducted with a very large number of child participants or with less than 100 participants, ranging from 4 to 99. Studies using quantitative methods, on the other hand, in most cases had 50–199 participants ($n=6$). One quantitative study was conducted with 35 child participants (Yin et al., 2020). Many studies included participants from non-dominant backgrounds or with special educational needs. However, only two studies

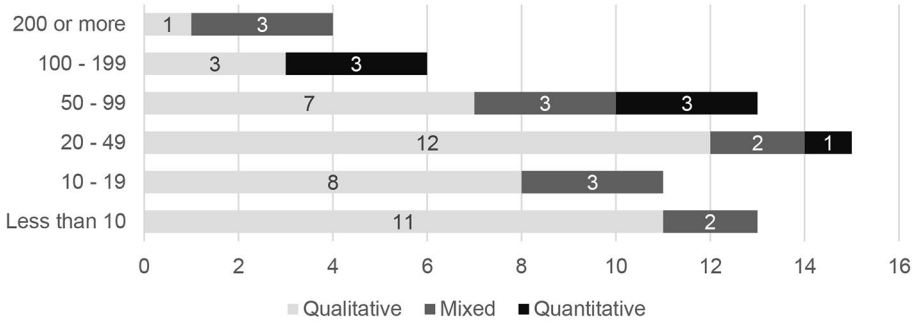


Fig. 2 Child participants in the reviewed studies in relation to the methods used

focused specifically on youth from non-dominant backgrounds (Brownell, 2020; Hsu et al., 2022), and three studies focused exclusively on inclusion and students with special needs (Giusti & Bombieri, 2020; Martin et al., 2020; Sormunen et al., 2020). In addition, one study specifically chose gifted students in their sample (Andersen et al., 2022).

Slightly over half of the studied projects had only collaborative tasks ($n=36$), 11 projects involved both collaborative and individual tasks, and in 11 projects, the participants worked on their own individual tasks. Four studies did not specify whether the project was built around collaborative or individual tasks. In most cases, the projects involved both traditional tangible tools and materials as well as digital devices and fabrication technologies ($n=54$). In five projects, the students worked entirely with digital design and making methods, and in 3 cases, only with traditional tangible materials. Similarly, the outcomes of the project tasks were mainly focused on designing and building artifacts that included both digital and material elements ($n=31$), or the project included multiple activities and building of several artifacts that were either digital, material, or had both elements ($n=17$). Eleven projects included digital exploration without an aim to build a design artifact as a preparatory activity, whereas one project was based solely on digital exploration as the making activity. Material artifacts without digital elements were made in seven of the studied projects, and six concentrated solely on digital artifact making.

The duration of the projects varied between two hours (Tisza & Markopoulos, 2021) and five years (Keune et al., 2022). The number of studies in each categorized project duration range, in relation to the methods used, is presented in Fig. 3. Over half of the projects lasted between 1 month and one year ($n=35$), nine were longer, lasting between 1 and 5 years, and 14 were short projects lasting less than one month. Three qualitative studies and one quantitative study did not give any indication of the duration of the project. Most of the projects of qualitative studies took at least one month ($n=32$), whereas projects in mixed method studies usually were shorter than three months ($n=10$). On the other hand, quantitative studies usually investigated projects that were either shorter than three months ($n=4$) or longer than one year ($n=2$).

A multitude of different types of data was used in the reviewed studies. The data collection methods utilized by at least three reviewed studies are presented in Table 3. Qualitative studies usually utilized several (2 to 6) different data gathering methods ($n=31$), and all mixed method studies used more than one type of data (2 to 6). The most common data collection methods in qualitative studies were video data, interviews, and ethnographic

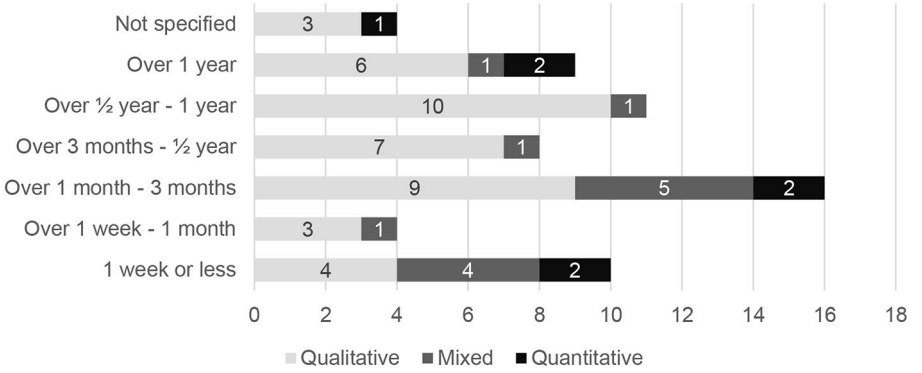


Fig. 3 Duration of the studied projects in relation to the methods used

observations combined with other data, such as design artifacts, photographs, and student portfolios. In addition to the data types specified in Table 3, some studies used more unusual data collection methods such as lesson plans (Herro et al., 2021b), the think-aloud protocol (Friend & Mills, 2021; Impedovo & Cederqvist, 2023), and social networks (Tenhovirta et al., 2022). Eleven qualitative studies used only one type of data, mainly video recordings ($n=9$). Mixed method studies, on the other hand, relied often on interviews, pre-post measurements, surveys, and video data. In addition to the data types in Table 3, mixed-method studies utilized biometric measurements (Hsu et al., 2022; Lee, 2021), lesson plans (Falloon et al., 2022), and teacher assessments (Doss & Bloom, 2023). In contrast to the qualitative and mixed method studies, all quantitative studies, apart from one (Yin et al., 2020), used only one form of research data, either pre-post measurements or surveys.

The findings of the data collection methods are similar to the previous literature review of Papavlasopoulou and colleagues (2017) regarding the wide variety of data types used in qualitative and mixed-method studies. However, when compared to their findings on specific types of research data used, video recordings have become the most popular way of collecting data in recent years, replacing interviews and ethnographic observations.

Research interests and findings of the reviewed studies

Seven categories of research interests emerged from the inductive coding of the reviewed studies. The categories are presented in Table 4 in relation to the research methods and educational levels of the participating children. Five qualitative studies, four mixed methods studies, and two quantitative studies had research interests from more than one category. Processes, activity, and practices, as well as sociomateriality in maker education, were studied exclusively with qualitative methods, and, on the other hand, nearly all studies on student motivation, interests, attitudes, engagement, and mindset were conducted with mixed or quantitative methods. In the two biggest categories, most of the studies utilized qualitative methods. Studies conducted with mixed or quantitative methods mainly concentrated on two categories: student learning and learning opportunities and student motivation, interests, attitudes, engagement, and mindset. In the following section, the research interests and findings for each category will be presented in detail.

Table 3 Data collection methods most used in the reviewed studies. Abbreviations: qualitative (QUAL); quantitative (QUAN); mixed (MIX); video (VID); interview (INT); ethnographic observations (ETH); pre-post-test, -survey, -interview, or -assessment (PPT); design artifacts (DAR); survey (SUR); photographs (PHO); self-assessment or reflection (SAS); portfolios or student writings (PFL); teacher reflections (TRF); rubric observations (RUB); student presentations (SPR); audio recordings (AUD)

	VID	INT	ETH	PPT	DAR	SUR	PHO	SAS	PFL	TRF	RUB	SPR	AUD
QUAL	28	20	20	3	11	1	7	4	4	2	2	2	3
MIX	4	7	3	7	3	5	1	1	1	2	1	1	
QUAN				5		3							
Total	32	27	23	15	14	9	8	5	5	4	3	3	3

Nearly half of the reviewed studies ($n=30$) had a research interest in either student learning through making activities in general or learning opportunities provided by such activities. Five qualitative case studies (Giusti & Bombieri, 2020; Hachey et al., 2022; Hagerman et al., 2022; Hartikainen et al., 2023; Morado et al., 2021) and two mixed method studies (Martin et al., 2020; Vuopala et al., 2020) investigated the overall educational value of maker education. One of these studies was conducted in early childhood education (Hachey et al., 2022), and two in the context of inclusion in primary and lower secondary education (Giusti & Bombieri, 2020; Martin et al., 2020). They all reported positive findings on the development of children's identity formation and skills beyond subject-specific competencies, such as creativity, innovation, cultural literacy, and learning skills. The studies conducted in the context of inclusion especially emphasized the potential of maker education in pushing students with special needs to achieve goals exceeding their supposed cognitive abilities (Giusti & Bombieri, 2020; Martin et al., 2020). Three studies (Forbes et al., 2021; Kumpulainen et al., 2020; Xiang et al., 2023) investigated student learning through the Maker Literacies Framework (Marsh et al., 2018). They also reported positive findings on student learning and skill development in early childhood and primary education, especially on the operational dimension of the framework, as well as on the cultural and critical dimensions. These positive results were further confirmed by the reviewed studies that investigated more specific learning opportunities provided by maker education on developing young people's creativity, innovation skills, design thinking and entrepreneurship (Liu & Li, 2023; Timotheou & Ioannou, 2021; Weng et al., 2022a, b), as well as their 21st-century skills (Iwata et al., 2020; Tan et al., 2021), and critical data literacies and critical thinking (Stornaiuolo, 2020; Weng et al., 2022a).

Studies that investigated subject-specific learning most often focused on STEM subjects or programming and computational thinking. Based on the findings of these studies, maker-centered learning activities are effective but underused (Mørch et al., 2023). Furthermore, in early childhood education, such activities may support children taking on the role of a STEM practitioner (Hachey et al., 2022) and, on the other hand, provide them access to learning about STEM subjects beyond their grade level, even in upper secondary education (Tofel-Grehl et al., 2021; Winters et al., 2022). However, two studies (Falloon et al.,

Table 4 Research interests of the reviewed studies on different educational levels. Abbreviations: qualitative (QUAL), mixed (MIX), quantitative (QUAN), early childhood education (ECE), primary education (PRIM), lower secondary education (LSEC), and upper secondary education (USEC)

	QUAL	MIX	QUAN	ECE	ECE & PRIM	ECE & LSEC	PRIM	LSEC	USEC	Total
Student learning and learning opportunities	17	8	5	2	2	1	12	12	1	30
Facilitation and teaching practices	11	1	1			1	5	6	1	13
Processes, activities, and practices	11			1			5	4	1	11
Student motivation, interests, attitudes, engagement, and mindset		6	2				4	4		8
Collaboration	5	1					4	2		6
Research methods	2	2	1				1	4		5
Sociomateriality	3						1	2		3

2022; Forbes et al., 2021) highlighted that it cannot be assumed that students naturally learn science and mathematics conceptual knowledge through making. To achieve learning in STEM subjects, especially science and mathematics, teachers need to specifically identify, design, and focus the making tasks on these areas. One study also looked at the effects of the COVID-19 pandemic on STEM disciplines and found the restrictions on the use of common makerspaces and the changes in the technologies used to have been detrimental to student's learning in these areas (Dúo-Terrón et al., 2022).

Only positive findings emerged from the reviewed studies on how digital making activities promote the development of programming and computational thinking skills and practices (Iwata et al., 2020; Liu & Li, 2023; Yin et al., 2020) and understanding of programming methods used in AI and machine learning (Ng et al., 2023). Experiences of fun provided by the making activities were also found to enhance further student learning about programming (Tisza & Markopoulos, 2021). One study also reported positive results on student learning of academic writing skills (Stewart et al., 2023). There were also three studies (Brownell, 2020; Greenberg et al., 2020; Wargo, 2021) that investigated the potential of maker education to promote equity and learning about social justice and injustice, as well as one study that examined learning opportunities on sustainability (Impedovo & Cederqvist, 2023). All these studies found making activities and makerspaces to be fertile ground for learning as well as identity and community building around these topics.

The studies with research interests in the second largest category, facilitation and teaching practices ($n=13$), investigated a multitude of different aspects of this area. The studies on assessment methods highlighted the educational value of process-based portfolios (Fields et al., 2021; Riikonen, Kangas et al., 2020) and connected portfolios that are digital portfolios aligned with a connected learning framework (Keune et al., 2022). On the other hand, Walan and Brink (2023) concentrated on developing and analyzing the outcomes of a self-assessment tool for maker-centered learning activities designed to promote 21st-century skills. Several research interests emerged from the review related to scaffolding and implementation of maker education in schools. Riikonen, Kangas, and colleagues (2020) investigated the pedagogical infrastructures of knowledge-creating, maker-centered learning. It emphasized longstanding iterative, socio-material projects, where real-time support and embedded scaffolding are provided to the participants by a multi-disciplinary teacher team and ideally also by peer tutors. Multi-disciplinary collaboration was also emphasized by Pitkänen and colleagues (2020) in their study on the role of facilitators as educators in Fab Labs. Cross-age peer tutoring was investigated by five studies and found to be highly effective in promoting learning in maker education (Kumpulainen et al., 2020; Riikonen, Kangas, et al., 2020; Tenhovirta et al., 2022; Weng et al., 2022a; Winters et al., 2022). Kajamaa and colleagues (2020) further highlighted the importance of team teaching and emphasized moving from authoritative interaction with students to collaboration. Sormunen and colleagues' (2020) findings on teacher support in an inclusive setting demonstrated how teacher-directed scaffolding and facilitation of student cooperation and reflective discussions are essential in promoting inclusion-related participation, collaboration skills, and student competence building. One study (Andersen et al., 2022) took a different approach and investigated the possibilities of automatic scaffolding of making activities through AI. They concluded that automated scaffolding has excellent potential in maker education and went as far as to suggest that a transition should be made to it. One study also recognized the potential of combining making activities with drama education (Walan, 2021).

Versatile aspects of different processes, activities, and practices in maker-centered learning projects were studied by 11 qualitative studies included in this review. Two interlinked studies (Davies et al., 2023; Riikonen, Seitamaa-Hakkarainen et al., 2020) investigated practices and processes related to collaborative invention, making, and knowledge-creation in lower secondary education. Their findings highlighted the multifaceted and iterative nature of such processes as well as the potential of maker education to offer students authentic opportunities for knowledge creation. Sinervo and colleagues (2021) also investigated the nature of the co-invention processes from the point of view of how children themselves describe and reflect their own processes. Their findings showed how children could recognize different external constraints involved in their design and the importance of iterative ideation processes and testing the ideas through prototyping. Innovation and invention practices were also studied by two other studies in both formal and informal settings with children from the primary level of education (Leskinen et al., 2023; Skåland et al., 2020). Skåland and colleagues' (2020) findings suggest that narrative framing, that is, storytelling with the children, is an especially fruitful approach in a library setting and helps children understand their process of inventing. Similar findings were made in the study on the role of play in early childhood maker education (Fleer, 2022), where play enhanced design cognition and related processes and helped young children make sense of design. On the other hand, Leskinen and colleagues (2023) showed how innovations are jointly practiced in the interaction between students and teachers. They also emphasized the importance of using manifold information sources and material elements in creative innovation processes.

One study (Kajamaa & Kumpulainen, 2020) investigated collaborative knowledge practices and how those are mediated in school makerspaces. They identified four types of knowledge practices involved in maker-centered learning activities: orienting, interpreting, concretizing, and expanding knowledge, and how discourse, materials, embodied actions, and the physical space mediate these practices. Their findings also showed that due to the complexity of these practices, students might find maker-centered learning activities difficult. The sophisticated epistemic practices involved in collaborative invention processes were also demonstrated by the findings of Mehto, Riikonen, Hakkarainen, and colleagues (2020a). Other investigators examined how art-based (Lindberg et al., 2020), touch-related (Friend & Mills, 2021), and information (Li, 2021) practices affect and can be incorporated into making. All three studies reported positive findings on the effects of these practices on student learning and, on the other hand, on the further development of the practices themselves.

Research interests related to student motivation, interests, attitudes, engagement, and mindset were studied by eight reviewed articles, all conducted with either mixed (n=6) or quantitative methods (n=2). The studies that investigated student motivation and engagement in making activities (Lee, 2021; Martin et al., 2020; Ng et al., 2023; Nikou, 2023) highlighted the importance of social interactions and collaboration as highly influential factors in these areas. On the other hand, positive attitudes towards collaboration also developed through these activities (Nguyen et al., 2023). Making activities conducted in the context of equity-oriented pedagogy were found to have great potential in sustaining non-dominant youths', especially girls', positive attitudes toward science (Hsu et al., 2022). On the other hand, a similar potential was not found in the development of interest in STEM subjects with autistic students (Martin et al., 2020). Two studies investigated student mindsets in maker-centered learning activities (Doss & Bloom, 2023; Vongkulluksn et al., 2021).

Doss and Bloom (2023) identified seven different student mindset profiles present in making activities. Over half (56.67%) of the students in their study were found to share the same mindset profile, characterized as: 'Flexible, Goal-Oriented, Persistent, Optimistic, Humorous, Realistic about Final Product' (Doss & Bloom, 2023, p. 4). In turn, Vongkulluksn and colleagues (2021) investigated the growth mindset trends for students who participated in a makerspace program for two years in an elementary school. Their findings revealed positive results of how makerspace environments can potentially improve students' growth mindset.

Six studies included in this review analyzed collaboration within making activities. Students were found to be supportive and respectful towards each other as well as recognize and draw on each other's expertise (Giusti & Bombieri, 2020; Herro et al., 2021a, b). The making activities and outcomes were found to act as mediators in promoting mutual recognition between students with varying cognitive capabilities and special needs in inclusive settings (Herro et al., 2021a). Furthermore, a community of interest that emerges through collaborative making activities was also found to be effective in supporting interest development and sustainability (Tan et al., 2021). Students were observed to divide work and share roles during their team projects, usually based on students' interests, expertise, and skills (Herro et al., 2021a, b). The findings of Stewart et al.'s (2023) study suggested that when roles are preassigned to the team members by teachers, it decreases student stress in maker activities. However, if dominating leadership roles emerged in a team, that was found to lead to less advanced forms of collaboration than shared leadership within the team (Leskinen et al., 2021).

Sociomaterial aspects of making activities were in the interest of three reviewed studies (Kumpulainen & Kajamaa, 2020; Mehto et al., 2020a; Mehto et al., 2020b). Materials were shown to have an active role in knowledge-creation and ideation in open-ended maker-centered learning (Mehto et al., 2020a), which allows for thinking together with the materials (Mehto et al., 2020b). The task-related physical materials act as a focal point for team collaboration and invite participation (Mehto et al., 2020b). Furthermore, a study by Kumpulainen and Kajamaa (2020) emphasized the sociomaterial dynamics of agency, where agency flows in any combination between students, teachers, and materials. However, the singularity or multiplicity of the materials potentially affects the opportunities for access and control of the process (Mehto et al., 2020b).

In addition to empirical research interests, five studies focused on developing research methods for measuring and analyzing different aspects of maker education. Biometric measurements were investigated as a potential data source to detect engagement in making activities (Lee, 2021). Yin and colleagues (2020) focused on developing instruments for the quantitative measurement of computational thinking skills. On the other hand, Timotheou and Ioannou (2021) designed and tested an analytic framework and coding scheme to analyze learning and innovation skills from qualitative interviews and video data. Artificial intelligence as a potential, partially automated tool for analyzing CSCL artifacts was also investigated by one study (Andersen et al., 2022). Finally, Riikonen, Seitamaa-Hakkarainen, and colleagues (2020) developed visual video data analysis methods for investigating collaborative design and making activities.

Slightly over half of the reviewed studies ($n=33$) made clear suggestions for future research. Expectedly, these studies suggested further investigation of their own research interests. However, across the studies, five themes of recommendations for future research interests and designs emerged from the data:

1. *Studies conducted with diverse range of participants*, *pedagogical designs*, *and contexts* (Hartikainen et al., 2023; Kumpulainen & Kajamaa, 2020; Leskinen et al., 2023; Lindberg et al., 2020; Liu & Li, 2023 Martin et al., 2020; Mehto et al., 2020b; Nguyen et al., 2023; Sormunen et al., 2020; Tan et al., 2021; Weng et al., 2022a, b; Yin et al., 2020).

2. *Longitudinal studies* to confirm the existing research findings, further develop pedagogical approaches to making, and to better understand the effects of maker education on students later in their lives (Davies et al., 2023; Fields et al., 2021; Kumpulainen et al., 2020; Kumpulainen & Kajamaa, 2020; Stornaiuolo, 2020; Tisza & Markopoulos, 2021; Walan & Brink, 2023; Weng et al., 2022a).

3. *Development of new methods and applying existing methods in different conditions* (Doss & Bloom, 2023; Kumpulainen et al., 2020; Leskinen et al., 2021; Mehto et al., 2020b; Mørch et al., 2023; Tan et al., 2021; Timotheou & Ioannou, 2021; Tisza & Markopoulos, 2021).

4. *Identifying optimal conditions and practices* for learning, skill, and identity development through making (Davies et al., 2023; Fields et al., 2021; Hartikainen et al., 2023; Tofel-Grehl et al., 2021).

5. *Collaboration* from the perspectives of how it affects processes and outcomes of making activities and, on the other hand, how such activities affect collaboration (Pitkänen et al., 2020; Tisza & Markopoulos, 2021; Weng et al., 2022a).

Discussion and conclusions

This systematic literature review was conducted to describe the development of research on maker education in the early 2020s. Sixty-two studies from the initial 700 studies identified from the three major educational research databases were included in the review. The qualitative analysis of the reviewed studies revealed some interesting developments in the field. Overall, the research on maker education appears to be active. Maker education seems to be attracting interest from researchers around the globe. However, two epicenters of research, North America and Scandinavia, namely Finland, appear to have an active role in maker research.

Most studies relied on rich qualitative data, often collected using several methods. Video recordings have become a popular way to collect data in maker education research. Although qualitative methods remained the dominant methodological approach in the field (Papavlasopoulou et al., 2017; Rouse & Rouse, 2022; Schad & Jones, 2020), mixed and quantitative methods were used in nearly a third of the reviewed studies. These studies mainly measured learning outcomes or participants' motivation, interests, attitudes, engagement, and mindsets. There was a great variety in the duration of the maker projects and the number of participants. The projects lasted from less than a day up to five years, and the number of participants varied similarly from one to nearly six hundred. Methodological development was also within the research interests of several studies in this review. Developments were made both in qualitative and quantitative methodologies. Such methodological development was one of the research gaps identified in the previous literature reviews (e.g., Schad & Jones, 2020).

The analysis of the reviewed studies revealed an interesting shift in research on maker education from informal settings to formal education. Our review revealed that most studies

were conducted exclusively in formal education and often as part of the curricular activity. The need for this development was called for in the previous literature reviews (Papavlasopoulou et al., 2017; Rouse & Rouse, 2022). However, only a handful of studies were conducted in early childhood education. Winters and colleagues' (2022) study adopted a very interesting setting where children from early childhood education worked together and were mentored by students from lower secondary education. This type of research setting could have great potential for future research in maker education.

Another research gap identified in the previous literature reviews was the need to study and measure a wide variety of potential learning opportunities and outcomes of maker education (Lin et al., 2020; Rouse & Rouse, 2022; Schad & Jones, 2020). The analysis revealed that new research in the field is actively filling this gap. Skills that go beyond subject-specific content and the development of participants' identities through making activities were especially actively studied from various perspectives. The findings of these studies were distinctively positive, corresponding with the conclusions of the previous literature reviews (e.g., Papavlasopoulou et al., 2017; Schad & Jones, 2020; Vossoughi & Bevan, 2014). This potential of maker education should be recognized by educators and policymakers, especially when the advancements in AI technologies will forefront the need for the humane skills of working creatively with knowledge and different ways of knowing, empathic engagement, and collaboration (e.g., Liu et al., 2024; Markauskaite et al., 2022; Qadir, 2023; World Economic Forum, 2023). Some of these studies also addressed the issue of promoting equity through maker education, which was called for in the previous literature review (Rouse & Rouse, 2022; Vossoughi & Bevan, 2014). However, considering the small number of these studies, more research will still be needed.

The two other popular research interest categories that emerged from the analysis were facilitation and teaching practices as well as processes, activities, and practices involved in making – both identified as research gaps in the previous literature reviews (Iivari et al., 2016; Papavlasopoulou et al., 2017; Rouse & Rouse, 2022; Schad & Jones, 2020; Vossoughi & Bevan, 2014). The teaching practices and scaffolding of making activities were investigated from different aspects, such as assessment methods, implementation of maker education in schools, and cross-age peer tutoring. The results of these studies highlighted the positive effects of multi-disciplinary collaboration and peer tutoring. Such pedagogical approaches should be more widely promoted as integral parts of the pedagogical infrastructure in schools. However, this calls for measures from policymakers and school authorities to enable such collaborative ways of teaching that extend beyond the traditional structures of school organizations. Furthermore, although research on this area has been active and multi-faceted, the facilitation of maker education in inclusive settings especially calls for further investigation. In terms of processes, practices, and activities involved in making, the reviewed studies investigated a variety of aspects that revealed the sophisticated epistemic practices involved and the importance of concrete making, prototyping, and iterative ideation in maker-centered learning activities. These studies further highlighted the potential of maker education to offer students authentic opportunities for knowledge creation. Studies also examined collaboration and sociomateriality involved in maker education. Especially sociomateriality is a relatively new, emerging area of research in maker education.

The reviewed studies identified five research gaps that require further investigation: (1) conducting studies with a diverse range of participants, pedagogical designs, and contexts; (2) carrying out longitudinal studies; (3) developing new methods and applying existing

methods in different settings; (4) identifying the most effective conditions and practices for learning, skill development and identity formation in maker education, and (5) understanding how collaboration affects the processes and outcomes of making activities and vice versa. In addition to the research gaps identified by reviewed studies, the analysis revealed additional gaps. Studies conducted in early childhood education and inclusive settings remain especially under-represented, although maker pedagogies have been found to have great potential in these areas. Similarly, many researchers have recognized the potential of maker education to promote equality between children from different backgrounds and genders. Still, only a handful of studies investigated these issues. Thus, more research is needed, especially on best practices and pedagogical approaches in this area. Furthermore, the processes involved in and affecting maker-centered learning call for further investigations.

The field has matured based on the analysis of the reviewed studies. It is moving from striving to understand what can be achieved to investigating the underlying conditions behind learning through making, how desired outcomes can be best achieved, as well as how the processes involved in making unfold, what the effects are in the long run, and how to understand best and measure different phenomena related to making. Furthermore, researchers are looking into more and more opportunities to expand the learning opportunities of maker education by combining them with other creative pedagogies and applying them to projects that seek to introduce subject-specific content beyond STEM to students.

This systematic literature review has several limitations. The typical limitations of most review studies, the potential loss of search results due to limited search terms and databases used, apply to this review. For example, more culturally diverse search results might have been reached with the addition of other databases and further search terms. However, the search string was carefully designed and tested to include as many common terms used in maker education research as possible, including possible variations. Furthermore, the three databases used in the search, Scopus, ERIC, and EBSCO, are regarded as the most comprehensive databases of educational research available. Thus, although some studies might not have been identified because of these limitations, it can be assumed that this review gives a comprehensive enough snapshot of research on maker education in the early years of the 2020s.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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