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Two Decades in the Making: A Scoping Review on Research on Digital Making and its Potential for Digital Empowerment in Non-formal Settings

FabLabs and makerspaces offer unprecedented opportunities for digital empowerment, especially for children and adolescents. However, reviews on making with regard to empowerment are lacking. We identified *n* = 180 publications on digital making with children and adolescents and, after categorizing them regarding formal criteria and formality of settings, identified the main topics in publications on digital making in non-formal settings. Results revealed a great demand for empirical studies with experimental designs. Three main topics emerged: domain-specific determinants of participation, equity, and skills and competencies. Implications for further research and limitations as well as implications for digital empowerment processes are discussed.

Keywords: maker movement; digital empowerment; maker education; children; scoping review

1. Introduction

Rapid technological advancement transforms everyday life in an increasing pace, confronting children and adolescents with unique challenges. Although most members of the so-called net generation (Tapscott, 2009) are familiar with advanced technology as consumers, many of them may not know how to actively use it (Blikstein et al., 2017). However, with growing technical opportunities, it is becoming increasingly important that children and adolescents learn how to use technology for pursuing their own goals. This process of digital empowerment might even encourage them to apply new technology for the benefit of their peers and the society as a whole (Mäkinen, 2006). To promote such processes of digital empowerment, it is helpful to foster "awareness, motivation, technical access and competence" in children and adolescents, as well as to provide them with "a possibility for constructive participation" (Mäkinen, 2006, p. 391).

A viable starting point for digital empowerment processes is provided by the increasingly popular phenomenon of digital making, defined as "the creative process of making a product or digital artefact", including "coding and using programming skills, but also other creative uses of digital tools to make new products" (Sefton-Green, 2013, p. 2). According to Holbert (2016b, p. 34) making is "a literacy – a way of reading the world as a collection of rescources and materials to be composed, repurposed, and rearranged. Making is 'what if?' and 'why not?'– of positioning oneself as having power – of taking responsibility for challenges and obstacles faced by oneself and one's community and enacting solutions".

With many young people, digital making arouses great enthusiasm for the creative use of technology and might therefore provide children and adolescents with unique opportunities for individual and collective digital empowerment processes. Accordingly, some studies on making have already suggested ways in which making can contribute to empowerment processes (Grandl et al., 2020; Reichenbach & Reynante, 2019; Thanapornsangsuth & Holbert, 2020). However, making is a very broad research field and most of the relevant studies only implicitly consider the issue of empowerment by mentioning related constructs. Therefore, a review is warranted that thoroughly examines the current research landscape of digital making through the lens of digital empowerment. As is the custom with reviews, this review starts with an overview on bibliographic characteristics, methodological approaches, quantitative study designs and approaches to qualitative data analysis applied in the studies. After considering the formality of settings, the main topics of research of digital making in non-formal settings are scrutinized for implications for the potential for digital empowerment processes.

2. The maker movement and maker education

2.1 FabLabs, the maker movement, makerspaces, making and maker education

So-called FabLabs or Fabrication Laboratories are open workshops with a mission to provide the general public with access to digital manufacturing technologies free of charge or at a reasonable price (Gershenfeld, 2007). Thus, they may contribute to bridging the ever-increasing gap of individual skills and competency requirements arising from the accelerating trend of digitalization (Hernandez-de-Menendez et al., 2020).

The first FabLab opened at the Massachusetts Institute of Technology (MIT) in the year 2002. In the following years, countless FabLabs and other makerspaces were established worldwide. The term FabLab is a MIT trademark that is directly linked to the work of Gershenfeld (2007) and implies the use of specified equipment. In contrast, the term makerspace, as defined by Sheffield et al. (2017), is a rather broad concept that relates to all flavors of places that provide "the space, resources, and opportunity required for a collective to *make* an artefact or product that is often unique to the maker" (p. 149, italics in the original).

Just as makerspaces are diverse, maker activities also span a broad range of "activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a 'product' of some sort that can be used, interacted with, or demonstrated" (Martin, 2015, p. 31). This corresponds to the approach of Honey and Kanter (2013, p. 4) who described making as "to build or adapt objects by hand, for the simple personal pleasure of figuring out how things work" or Hatch (2014) who stressed the construction of physical objects as a feature of the maker movement in his "Maker Movement Manifesto". The maker movement consists of a "growing number of people who are engaged in the creative production of

artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" (Halverson & Sheridan, 2014, p. 496).

While participation in the maker movement is possible without using advanced technology provided at a makerspace, the maker movement is nevertheless closely linked to digital technology. As we are interested in the potential for digital empowerment processes, this review focuses on digital making, which implies the use of some kind of technology (Sefton-Green, 2013).

As the maker movement gained popularity in practice, interest in educational contexts increased as well (Martin et al., 2018). Although there are different perspectives on the definition of making (Martin, 2015), today, terms like maker education (Bevan, 2017) are well established.

2.2 Making in non-formal settings as a starting point for digital empowerment processes

Making has sparked research interest regarding both formal and non-formal settings (Bevan, 2017; Papavlasopoulou et al., 2017; Schad & Jones, 2020; Ventä-Olkkonen et al., 2019; Willett, 2016). Regarding formal contexts, many of the existing reviews on making concluded that making holds great potential for broadening participation in science and STEM-learning (Bevan, 2017; Papavlasopoulou et al., 2017). However, instead of exploring how to foster participation, the purpose of maker activities in formal settings often involves meeting externally defined educational objectives, for example focusing on students' understandings of circuit features (Litts et al., 2017). Weiner et al. (2017), however, emphasized that there is more to making than knowledge acquisition regarding technical processes or STEM-competencies. Along the same lines, Willett (2016) highlighted that particularly making in non-formal settings,

as compared to formal settings, enables more playful and active learning out of one's own interest and therefore more valuable experiences.

Empowerment is about the "individual determination over one's own life" (Rappaport, p. 121). Moreover, in accordance with the "Empowerment Model" by Rindner (2004, p. 80), in the context of empowerment, it is emphasized that "learning takes place in the real world", beyond "classroom learning". Thus, it makes sense to explore empowerment processes in non-formal, rather than in formal settings (Täubig, 2018). Along the same lines, the focus on making activities in non-formal settings is mostly on learner determined and learner initiated processes, while meeting learning objectives is merely a by-product (Stern & Sommerlad, 1999). Nevertheless, digital competencies are predominantly acquired in non-formal settings (Barclays, 2016; D21 Digital Index 19/20, 2020).

The decision to participate in maker activities in non-formal settings is self-initiated, and voluntary. At the same time, participation is a precondition for empowerment processes (Holcombe, 1995). It is determined by both person-related and environmental variables (Kröner, 2013). On the one hand, this can lead to unfavorable disparities, for example in terms of participation of children and adolescents from socially disadvantaged backgrounds or girls (Barton et al., 2017; Intel Corporation, 2014). On the other hand, especially non-formal settings like makerspaces could contribute to higher participation and more equity in education. As Ryoo and Barton (2018, p. 3) put it, making can "invite and engage youth (who may not normally consider themselves as 'good at science') into learning STEM-concepts and practices while creating personally-meaningful and innovative designs". Similarly, Halverson and Sheridan (2014, p. 503) highlighted that "[b]ringing the maker movement into the education conversation" may be "a bold step toward equity in education". Inspite of the

great potential of making outlined above, the full potential regarding equity might not have been realized effectively. This is reflected in the analysis of American covers of the "MAKE" magazine, which featured pictures of white men in 90% of the cases (Buechley, 2013). Thus, while Making may offer the potential to promote equity, it is also at risk of reinforcing normative contexts (Vossoughi et al., 2016).

Since participation is a precondition for empowerment processes, especially for marginalized groups, it might be important to examine the determinants of participation. However, before considering such specific questions, one should consider what research has been conducted on making with regard to digital empowerment processes in general. Therefore, in order to make reliable statements on the potential of digital making for digital empowerment processes, a review is needed that (1) goes beyond the few studies on making that explicitly refer to empowerment and (2) examines the broad field of research in an explorative way while (3) also considering questions of bibliographical characteristics and methodological specifications.

3. Review questions

The present scoping review builds on and extends previous related reviews with the following research questions:

(1) How are the available published studies on digital making in general distributed according to bibliographic characteristics and methodology?

(2) What proportion of the identified studies examines making in non-formal settings, which main topics of research emerge and to what extent do the studies provide implications for the potential of making in non-formal settings for digital empowerment processes?

4. Method

4.1 Scoping Reviews

For this review, we chose the methodology of a "scoping review" (Arksey & O'Malley, 2005). Scoping reviews serve the purpose of synthesizing main topics in research fields and thus provide a richly informed starting point for further inquiry, education, practice, and policy (Peterson et al., 2017). Scoping reviews provide an opportunity to cover a wide range of studies relating to a broad research question and they may include qualitative and quantitative studies with varying levels of methodological rigor (Tricco et al., 2016). Thus, they offer great potential for the exploration of broad emerging research fields like making that are teeming with diverse methodological approaches (Moher et al., 2015). As recommended by Levac et al. (2010) this scoping review provides a descriptive numerical summary and a qualitative thematic analysis.

4.2 Search Procedure

The electronic database Scopus (Elsevier, 2019) was used for the collection of literature. To acquire a literature corpus as broad as necessary but also to precisely aim at the core of the maker movement, the search string consisted of two dimensions: One containing terms directly related to digital making and the maker movement and one restricting these results to the focus on children and adolescents (see Table 1). The terms within each dimension were connected with a Boolean OR-operator, whereas the two dimensions were connected with an AND-operator. Thus, papers were retrieved that featured at least one term of both dimensions.

Table 1

Search String with Terms Related to Digital Making and Children and Adolescents

Dimensions	Search terms
Digital making	fablab*, "Fab-Lab", "Fabrication Laboratory", makerspace*, "Maker-Space", hackerspace*, "Maker Movement", "Maker Education", "Maker Mindset", "Maker Identity", "digital making", "digital fabrication"
Children and adolescents	*school*, child*, youth*, adolesc*, kids, teen*, young*, boy*, girl*, student*, pupil*, teacher*

We restricted our search to published papers from 2002 to 2019 in accordance with the foundation of the first FabLab in 2002. The aforementioned Scopus search on January 14th, 2020 yielded n = 791 results (n = 779 without duplicates). Moreover, we retrieved n = 18 relevant papers which had not been included in our initial database by scanning relevant existing literature reviews.

4.3 Screening the corpus

The publications were subjected to a two-stage screening process. After identifying and excluding duplicates, we screened the titles and abstracts, and excluded those articles that could be unmistakably judged irrelevant based on this information. In case of doubt, we proceeded with a full-text screening.

We included studies with the following characteristics:

(1) empirical research on a form of digital making with tangible objects
(2) based on a sample consisting of children or adolescents (from primary school age up to high school age)
(3) reporting results derived from qualitative, quantitative or mixed methods data

4.4 Data Analysis

As reported in the following paragraphs, we first categorized the included publications according to their bibliographic characteristics. Next, we scrutinized

methodological approaches, designs, analysis methods, and formality of the setting before conducting a thematic analysis of the main topics relevant for making in non-formal settings.

4.4.1 Bibliographic characteristics

We categorized publications according to the type of publication (journal article, conference paper, and book), the affiliation country of the first author and the year of publication as listed in the Scopus database.

4.4.2 Methodological approaches, designs and analysis methods

In a first step, we differentiated between studies with quantitative, qualitative and mixed methods approaches. Additionally, regarding the quantitative studies with intervention design, we differentiated between one-group posttest only designs (often referred to as "case study" in the publications), one-group pretest-posttest designs, quasi-experiments, and, as observational designs, quantitative longitudinal studies. While one might also have coded fully-fledged experiments or interventional longitudinal studies separately, these categories were empty and could thus be omitted. Moreover, we categorized the analysis methods of the quantitative studies (code & count, descriptive, inferential statistics, modelling; Jeong et al., 2014). Furthermore, the qualitative studies were categorized according to the data analysis methods applied (Jeong et al., 2014). We coded systematic text analyses or usage of some kind of coding framework as (qualitative) content analysis (Mayring, 2014). Analyses of interactions, conversations and discourses were coded as discourse analysis (Gee & Green, 1998). The category grounded theory included all the studies which explicitly stated to use open coding qualitative analytic techniques as proposed by Straus and Corbin (1990), constant comparative method (Glaser, 1965), or referred to "open coding". All studies

reporting analysis of emerging themes were coded as thematic analysis (Braun & Clarke, 2006). All other qualitative studies were coded as "other qualitative methods". This included studies that either applied less commonly used methods such as mapping or portfolio analysis or studies that did not explicitly mention either references to methodological literature or the name of the analysis method applied, but used an approach that was detailed enough to be identifiable. Studies which did neither report a reasonably detailed description nor methodological references regarding their methodological basis were categorized as "unspecified". We additionally reviewed the studies to determine whether, as recommended in the "Standards for Reporting Qualitative Research" (O'Brien et al., 2014), they cite a source, or name a specific approach to which they refer for their data analysis.

Studies with a mixed methods design were then analyzed separately according to the aforementioned categories for the quantitative and qualitative methods involved. Additionally, we checked for all mixed methods studies, whether they were embedded in an overarching design-based research process (DBR; The Design-Based Research Collective, 2003).

4.4.3 Formality of the setting

For the purpose of this review, we regard the distinction of the formality of the setting as formal vs. non-formal (Täubig, 2018, p. 417). The differentiation of the formality of the setting aimed at reflecting the overall degree of formality of the learning environment investigated in the study (Malcolm et al., 2003; Täubig, 2018). Hence, all maker activities taking place in FabLabs, autonomous makerspaces or makerspaces at public libraries, were coded as "making in non-formal settings". Note that the same holds true for maker activities that were located at schools but part of

summer camps or voluntary after-school activities. Thus, solely formal curriculum-based classroom maker activities at school were coded as "making in formal settings".

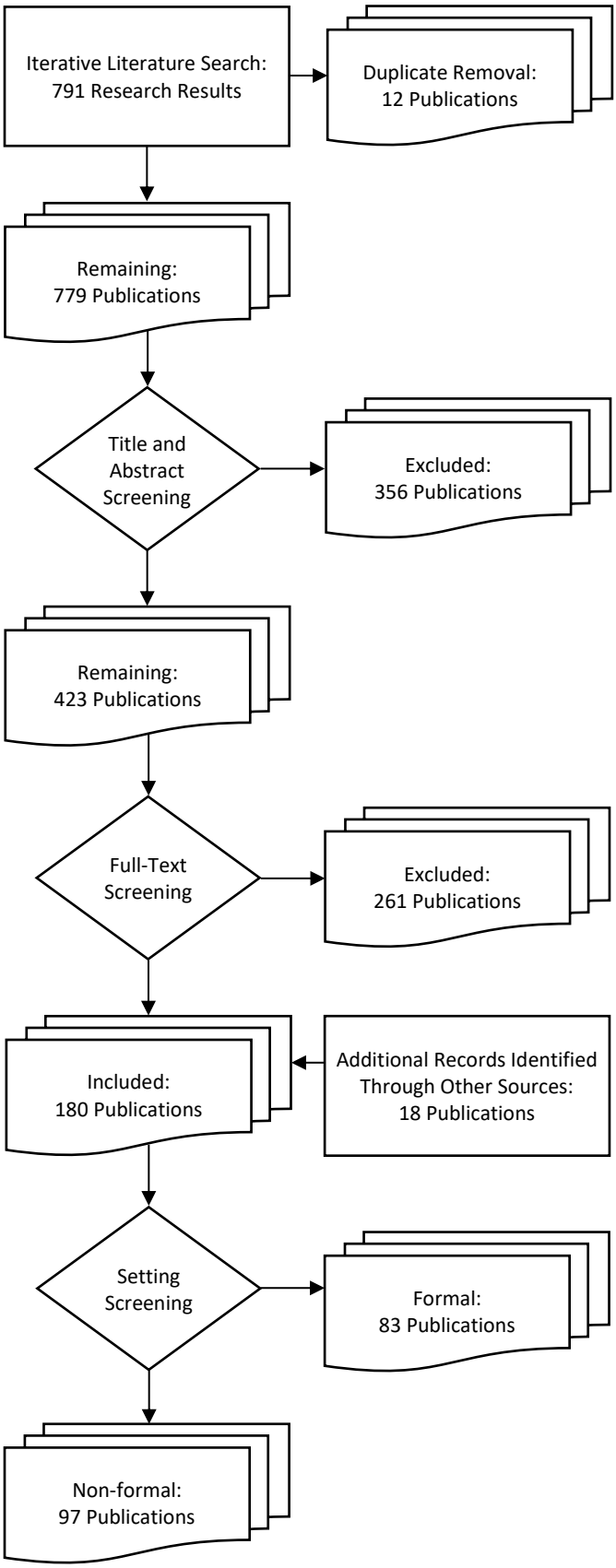
4.4.4. Thematic analysis of the research questions of publications on making in non-formal settings

To identify the main topics of research on digital making in non-formal settings, we conducted a thematic analysis (Braun & Clarke, 2006) of the studies' research questions. As a first step, we screened the studies to gain an overview of the research questions involved. In a second step, we labelled each study with a short description of its predominant topic. In a third step, we used these labels to inductively generate main topics and subtopics (Boyatzis, 1998; Braun & Clarke, 2006). For each (sub-)topic, we report prototypical studies and main results (Peterson et al., 2017). Moreover, we discuss practical implications for the potential of making in non-formal settings for digital empowerment processes (Peterson et al., 2017). For this purpose, as recommended by Aronson (1994) and Braun and Clarke (2006), we compare our results to the extant literature. In particular we relate them to the prerequisites for digital empowerment processes pointed out by Mäkinen (awareness, motivation, technical access, competence, and a possibility for constructive participation; 2006), and to the person-envirionment transaction framework suggested by Kröner (2013), which highlights the importance of person-related determinants like attitude and self-concept, as well as environment-related determinants like socioeconomic status.

5. **Results**

Figure 1

Flow Chart of Publication Identification and Numbers of Excluded and Included Publications



5.1 Results of the screening process

From the *n* = 779 unique articles retrieved from the database, about 46 percent (*n* = 356) could be already excluded as a result of title and abstract screening (see Figure 1). Among the *n* = 423 remaining articles, *n* = 261 could be excluded as the result of a full-text screening. Furthermore, *n* = 18 publications were retrieved via examination of the references in the aforementioned reviews on making and added to the corpus, resulting in *n* = 180 relevant articles remained for inclusion in this scoping review. After identifying the formality of the setting of the publications, *n* = 97 publications on making in non-formal settings remained for the thematic analysis.

5.2 Results of the categorization along bibliographic, content and methodological dimensions

5.2.1 Analysis of bibliographic dimensions

Approximately two thirds of the relevant publications were conference papers (63%, *n* = 113) and *n* = 67 publications were journal articles. No books or book chapters remained after the screening process. A large proportion of the publications originated from research groups based in the USA – as defined by first author's affiliation country (60%, *n* = 108) – followed by Finland, Germany, Belgium and England with five or more relevant publications (see Table 2).

Table 2

Ranking of the Included Publications by the Affiliation Country of the First Author

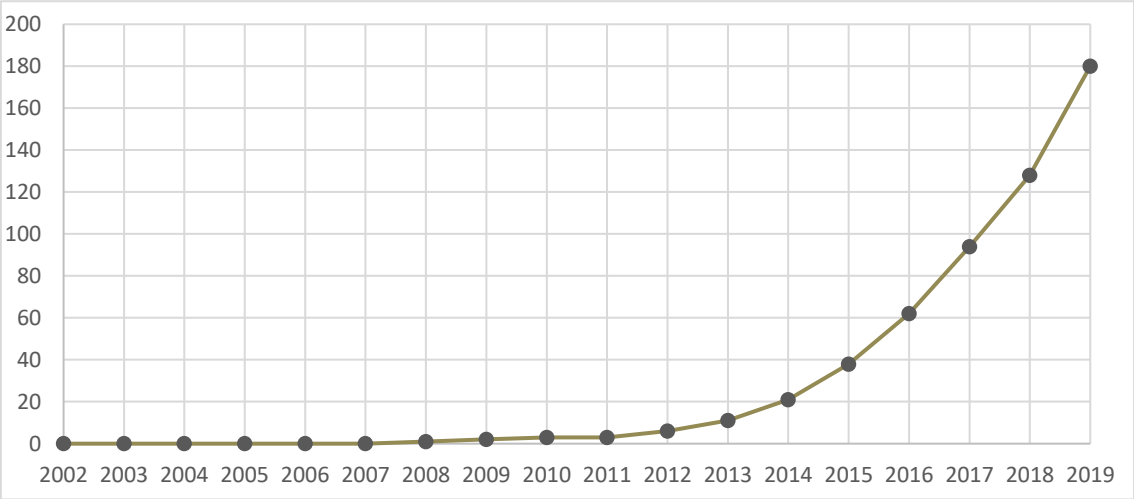
Rank	Affiliation Country	Number of Publications
1.	USA	108
2.	Finland	9
3.	Germany	7
4.	Belgium, England	5
5.	Austria, Brazil, Canada, Taiwan	4

6.	Australia, Denmark, Norway, Singapore, South Africa	3
7.	Israel, Italy, Spain	2
8.	China, India, Indonesia, Japan, Korea, Mexico, Netherlands, Scotland, Sweden	1

The oldest identified article was published in 2008, i.e. six years after the opening of the first FabLab at MIT. From then on, the number of relevant publications rose sharply (see Figure 2) with *n* = 52 publications in the year 2019.

Figure 2

Cumulative Number of Relevant Publications per Year



5.2.2 Analysis according to methodological approaches

Quantitative methods were used in *n = 25* publications, *n* = 132 publications pursued a qualitative approach. Mixed methods were reported in *n* = 23 publications.

Quantitative articles. A more fine-grained analysis of the quantitative publications (*n* = 25) revealed that most publications featured one-group posttest only designs. Moreover, we could not identify even a single study in the corpus with a fully-fledged experimental design. The most frequent analysis method in the publications with one-group posttest only designs was code and count, i.e. simple counting of quantified

qualitative data (see Table 3). A DBR approach was utilized by only one quantitative study, however without a methodological reference to DBR.

Table 3

Cross-Tabulation of Analysis Methods and Designs

Design	Analysis Method				
	Code & Count	Descriptive	Inferential Statistics	Modelling	Total
Observational Designs					
Quantitative Longitudinal			1	1	2
Intervention Designs					
One-Group Posttest Only	7	3	1		11
One-Group Pre-Posttest	2	2	5		9
Quasi-Experiment		1	2		3
Total	9	6	9	1	25

Note. The sample did neither include cross-sectional correlation studies nor fully-fledged experiments.

Qualitative articles. The qualitative studies (n = 132) featured varying analysis methods (see Table 4). The most frequent method with n = 31 was open coding according to the grounded theory (n = 22 with methodological reference). Almost a quarter of the qualitative publications (n = 31) were coded as unspecified. Among the qualitative studies, n = 5 papers featured the DBR-approach (thereof n = 3 with methodological reference to DBR). More than half of these studies (55%) did not report an explicit methodological reference for the used analysis method.

Table 4

Distribution of Analysis Methods and Number of Studies Featuring Methodological References

Analysis Method	Total	Thereof With Methodological Reference
Content Analysis	20	7

Discourse Analysis	9	9
Grounded Theory	31	22
Thematic Analysis	27	14
Other Qualitative Analysis	14	7
Unspecified	31	0
Total	132	59

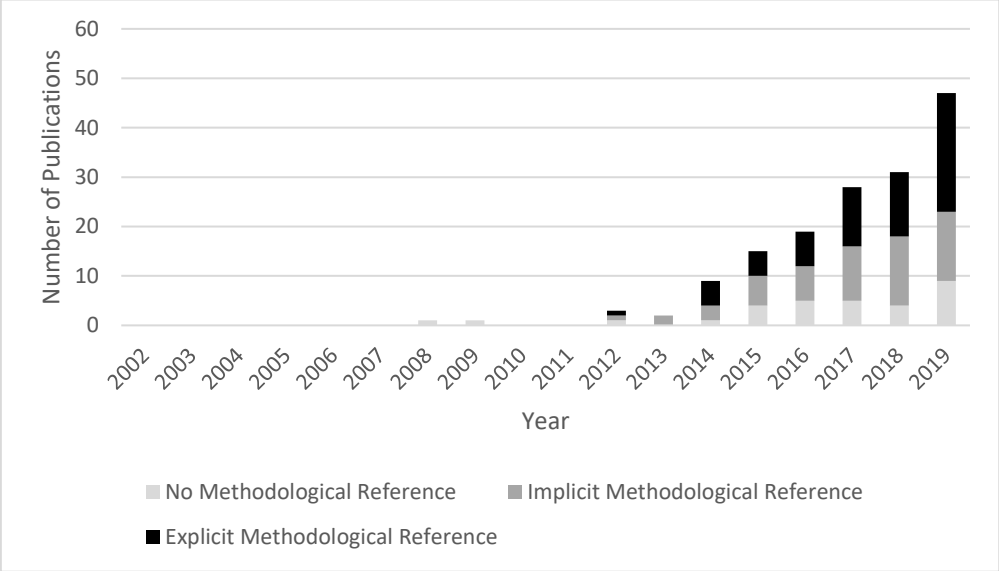
Mixed methods articles. Regarding study designs, $n = 10$ of the $n = 23$ mixed methods studies used one-group posttest only designs, $n = 9$ one-group pretest-posttest designs, $n = 3$ quasi-experiments with a control group, and $n = 1$ a longitudinal design. Regarding quantitative analysis methods, $n = 4$ publications used code & count, $n = 7$ descriptive statistics, $n = 10$ inferential statistics and $n = 1$ study modelling. Regarding qualitative analysis methods, $n = 7$ studies used some kind of qualitative content analysis, $n = 4$ studies a grounded theory approach, $n = 4$ thematic analysis, $n =$ another analysis method and $n = 6$ studies no detectable method at all.

Only $n = 6$ of the mixed methods studies cited methodological references for the qualitative analysis methods. Along the same lines, only $n = 7$ of the total n = 23 mixed methods studies included methodological references to an overaching strategy regarding their mixed methods approach. Of these $n = 7$ studies, $n = 4$ referred to the DBR approach ($n = 2$ with methodological reference to The Design-Based Research Collective, 2003). However, these $n = 4$ studies based on DBR covered only part of the process and did not report detailed revision cycles or the overall project.

Development of publication numbers over the course of time. We took a closer look at trends in the analysis methods applied in the qualitative studies. Figure 3 displays that the number of studies with explicit methodological reference has slightly increased over the years. However, there are still many qualitative publications on maker activities without explicit references to established qualitative analysis methods and sufficient descriptions of their analysis methods.

Figure 3

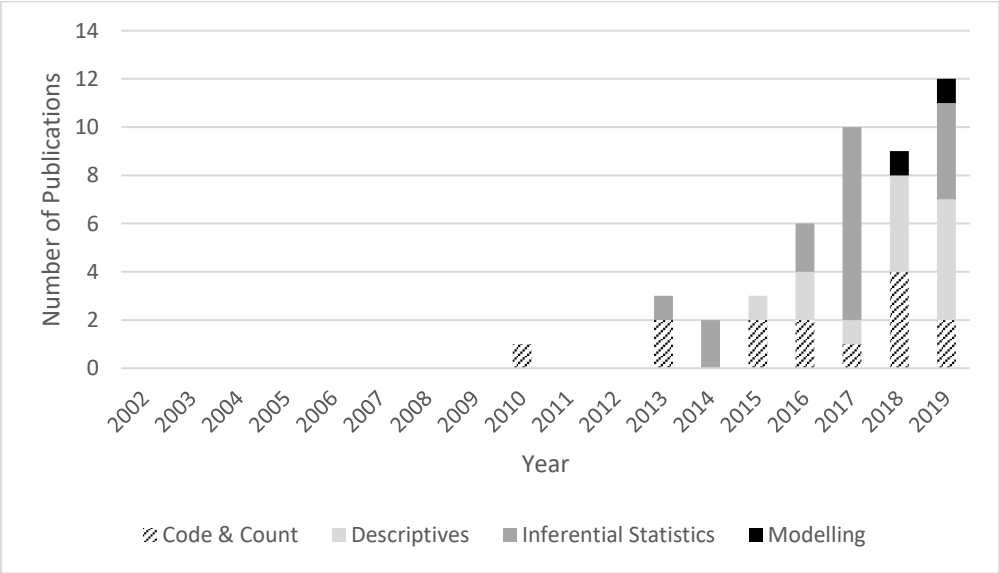
Distribution of Methodological References in Qualitative Studies Across the Years



As with qualitative studies, we also took a closer look at the – relatively few – quantitative studies. As shown in figure 4, the majority of these studies consisted of rather basic analyses. No distinct chronological positive tendencies in the distribution were discernible, except for the general growth in number in the years 2017 and 2019.

Figure 4

Distribution of Analysis Methods in Quantitative Studies Across the Years



5.2.3 Analysis of the setting

More than half of the studies in total focused on making in non-formal settings (*n* = 97 publications). Thus, *n* = 77 publications concentrated on making in formal settings or maker activities in both settings simultaneously (*n = 6* publications).

5.3 Thematic analysis of the main topics of research in research on making in non-formal settings

The thematic analysis of the research questions of the publications on making in non-formal settings revealed three dominant main topics: (1) domain-specific determinants of participation, (2) fostering equity and (3) the development of skills and competencies.

5.3.1 Main topic 1: Domain-specific determinants of participation

Many studies on making in non-formal settings (*n* = 23) dealt with domain-specific determinants of participation in maker activities, i.e., person-related determinants like attitude or self-concept that have a direct impact on the participation in making in particular. Domain-specific determinants can be distinguished from domain-general determinants, such as general personality traits (Kröner, 2013). The studies regarding domain-specific determinants of participation can be allocated to three phases: the awakening of catch-interest, the promotion of hold-interest (Bolkan & Griffin, 2018), and the formation of a maker identity.

Initially, the *(1) catch-interest* for the topic must be awakened in order to increase the motivation to register for a maker program or workshop. The qualitative study of Dreessen et al. (2016) is among the few that are dealing with the question of how to motivate young people to participate in maker activities for the first time. They noticed that a FabLab was an unfamiliar location, representing a major hurdle to participate in the workshops. Embedding the workshops into already existing

organizations and informal relationships between the involved adults and adolescents substantially lowered the participation hurdle.

Then, within the program or workshop, the promotion of *(2) hold-interest* is pivotal. Thus, conditions and design features should be chosen in a way that both interest and motivation will be maintained and the children and adolescents decide to participate in further activities. Keune and Peppler (2017) highlight the benefits of keeping track of maker activities in portfolios, Telhan et al. (2014) emphasize the importance of mentors, Tan et al. (2019) the promotion of fun and a community of like-minded people, Charlton and Poslad (2016) the perception of authenticity, Lorenzo (2017) the implemention of a motivating spiral design process, and Weibert et al. (2017) the inclusion of special interests like environmental awareness.

The time dimension also seems to be a key factor for the development of hold-interest: Dreessen and Schepers (2019) concluded that half-day workshops for school classes in FabLabs were too short to build meaningful relationships, and therefore claimed that longer and more frequent stays in FabLabs are advisable to successfully involve children in making.

In the long run, the formation of a *(3) maker identity* is important for a sustainable participation: If young people see making as part of their lifestyle and identity, they will also remain a permanent part of the maker community. Weiner et al. (2017) came to the conclusion that, surprisingly, none of the interviewed young makers insisted on the need for spacious facilities or costly equipment. Instead, they emphasized the importance of mentors, friends and families and fruitful relationships with teachers and peers.

5.3.2 Main topic 2: Fostering equity

With a total of *n* = 30 publications, fostering equity was the main topic identified in the largest number of studies. It goes without saying that these studies also touched issues like interest, motivation as determinants of maker activities and various variables as outcomes. However, these variables were merely peripheral, while fostering equity was in the spotlight. As outlined in the subsequent paragraph, these studies focused on promoting (1) equity in general, (2) equity with regard to children and youth from marginalized communities, or (3) equity related to gender.

Regarding *(1) fostering equity in general,* Peppler et al. (2018) derived three design principles for equitable makerspaces from a DBR study: mobility, a diversity of materials to allow a wide range of possibilities, and openness of the location for the young makers. In order to create equal opportunities in making, Ryoo et al. (2016) furthermore argued that it was an asset to adapt the activities to local knowledge and interests and to allow multiple starting points and routes. They recommended incorporating the principles "low floor, high ceilings and wide walls" (p. 51) which have also been mentioned by Bar-El and Zuckerman (2016). These principles implicate activities which are easy to get started on, yet offer considerable growth potential and multiple pathways. Moreover, Martin et al. (2018) emphasized the loosening and destabilising of hierarchies in the makerspace.

Many studies focussed on *(2) fostering the inclusion of children and adolescents from non-dominant communities or low-income backgrounds* in particular. Barton et al. (2016) highlighted the necessity to implement activities which allow adolescents to solve actual problems their community faces. For example, the invention of a "light up football", which enables adolescents to play football despite limited working streetlights, illustrates the potential to solve problems through making in an empowering way (Barton et al., 2016, p. 293). With regard to the engagement of

adolescents with different backgrounds, Akshay et al. (2018) highlighted the need to keep their specifics in mind and to react with appropriate scaffolding, i.e. providing purposeful help and guidance that are adapted to the target group.

As another aspect of equity, *(3) gender-related issues regarding equity of participation,* have received much attention in the field of making. Holbert and Thanapornsangsuth (2018) observed that during the maker activities, girls were often building things for others and while doing so explicitly kept their client in mind. These findings are in line with a study by Holbert (2016a) who reported that girls were particularly motivated and persistent if the maker activities were framed as related to their communities, meaning they could help someone by making.

5.3.3 Main topic 3: Development of skills and competencies

Even in the non-formal sector, maker activities were often directly associated with the promotion of certain skills and competencies. Representing the third main topic, $n = 16$ studies investigated the development of skills and competencies.

Most of the studies focused on the development of *(1) computational thinking*. Rode et al. (2015) observed that computational thinking, indicated by actions like analyzing, organizing and modelling data, working on different solutions and simulations, as well as using algorithms during making, was fostered by the participation of kids in a computer club in their neighborhood. Wagh et al. (2017) concluded that it is the direct and visible relationship between the physical system, in their case LED lights, and the code, which works or does not work, that serves as a bridge of direct feedback and stimulates the acquisition of computational thinking competencies.

In addition, *(2) mathematical competencies* were frequently highlighted. In their mixed methods study, Tillmann et al. (2014) investigated gains in mathematics test

scores and attitudes towards STEM induced by a summer mathematics enrichment maker-program. There were considerable improvements in all facets of mathematical competencies applied. Doorman et al. (2019) further indicated that integrating making in mathematics events fosters skills like problem-solving, collaboration and communication.

Beyond this, there were some studies on *(3) other competencies* including engineering or visualization skills. For example, Voigt et al. (2019) investigated the role of empathy, creativity and self-efficacy to facilitate design thinking skills in non-formal making workshops. In accordance with the definition of Brown (2008), these workshops aimed at empowering the participants to act as designers who use their "sensibility and methods to match people's needs with what is technologically feasible" (p. 86).

6. Discussion

6.1 Summary of results

The present review is based on a corpus of studies on digital making with children and adolescents. This corpus was initially explored regarding formal criteria such as bibliographic characteristics, indicating a clear focus in the US, and it was categorized regarding evidence-related issues like the methodological approaches used, the study designs applied and data analysis conducted. This revealed more occurrences of qualitative rather than quantitative studies, of weak quantitative study designs and of underanalyzed data. Moreover, the present study showed that more than half of the identified studies were focussing on making in non-formal settings, and it indicated which main topics of research were present within these studies. Main Topic 1 was about studies which explored domain-specific determinants of participation. Main topic 2 incorporated studies which aimed at fostering equity. Main topic 3 contained studies

dealing with how to foster the development of skills and competencies. These topics are discussed in the following.

6.1.1 Implications regarding bibliographic characteristics

Regarding bibliographic aspects, it comes with little surprise that the first authors of most studies are affiliated in the USA as the country of origin of the still relatively novel concept of making. Researchers around the globe should feel encouraged to join their colleagues from the US in the endeavor to accumulate empirical evidence on digital making based on strong theoretical frameworks.

6.1.2 Implications regarding further research in the field of making

Charting distributions of qualitative, quantitative and mixed methods studies, as well as evaluation methods over time did not reveal evidence for distinct change or trend towards increasing proportion of quantitative research in general and longitudinal and experimental studies in particular. While we do by no means want to devalue explorative or qualitative research, we nevertheless agree with Rosenshine and Furst (descriptive-correlational-experimental loop; 1973) that quantitative research has its merits, especially when the aim is to uncover causal relationships with experimental designs. Thus, even before the identification of any main topics, it is among the main results from our review that as the research field of digital making is coming of age, future research should make increasing use of (1) theory-based, hypothesis-testing approaches, (2) (quasi)-experimental designs featuring pre- and posttests as well as control groups, (3) precise terminolgy, and (4) suitable overarching research strategies like DBR based on mixed methods when aiming at the design of interventions.

Future studies on participation motivation, for example, may include experimental vignette studies as a feasible alternative to expensive hands-on making

interventions (Smolarczyk et al., 2021). Along the same lines, further longitudinal and experimental studies should be conducted to investigate the causal direction of effects as well as the persistence of the changes in competencies, attitudes and self-awareness that can potentially be achieved through maker activities and corresponding interventions.

6.1.3 Implications of the studies on digital making in non-formal settings for the potential for digital empowerment processes

In addition to the data-driven examination of the main topics of research, we will now discuss them in relation to the pertinent literature and with regard to their implications for digital empowerment processes. It is promising that the inductive examination of the research revealed three main topics that largely coincide with Mäkinen's (2006) prerequisites for digital empowerment processes. We can therefore assume that the nature of making offers great potential for digital empowerment processes or prerequisites of digital empowerment processes.

Main topic 1, domain-specific determinants of participation, highlighted the importance of domain-specific determinants as predictors for a sustainable participation in making in accordance with Kröner (2013). Furthermore, it indicated that the prerequisites of digital empowerment processes awareness and motivation, according to Mäkinen (2006), are already being researched in depth. The studies offered insights on how interest can be aroused, fostered and maintained in the long run. These studies provide useful guidelines for practitioners who want to implement empowering digital making in non-formal places. In order for empowerment processes to take place at all, it is therefore important to motivate children and young people to participate in digital making and then to keep them engaged.

Main topic 2, fostering equity, highlighted the importance of the socioeconomic status for individual participation (Kröner, 2013). It emphasized the necessity of access and the possibility for constructive participation for digital empowerment processes (Mäkinen, 2006). This access needs to be granted regardless of the gender, background or socioeconomic status. Here, however, the studies clearly demonstrated that there is a need to address certain groups of young people in particular and motivate them to participate voluntarily (e.g., girls, or children from marginalized communities). Many researchers highlighted the need to react to specific characteristics with an appropriate design of maker activities as well as low entry hurdles. In contrast to the aforementioned conjecture that the maker movement is inaccessible for particular groups of people, it was evident that researchers in great number focused on finding ways to successfully involve everyone in making, regardless of gender or social background. This clearly illustrated that the groups of people who benefit most from digital empowerment processes also need to be explicitly addressed with appropriate activities.

Main topic 3, development of skills and competencies, can be linked to the importance of the self-concept for participation (Kröner, 2013) and the need for competencies (Mäkinen, 2006). These studies indicated that maker activities in non-formal settings are particularly suitable for promoting the future-oriented ability of computational thinking, as well as further competencies, even beyond STEM. It was evident that digital empowerment processes have taken place that actually enabled children and young people to use technology for their own goals or for the benefit of society.

Digital empowerment processes have been a major factor in all three topics, and yet there are still large gaps regarding digital empowerment to be tackled in further research: Despite the promising findings regarding the design of digital making in non-

formal settings, large gaps remain to be filled regarding the role of participation determinants. There are many studies on person characteristics of minorized children or girls that already participate in making workshops. What is lacking, however, are studies on present non-makers that scrutinize their decision-making process regarding potential participation. Moreover, there is little evidence available regarding which design features of maker activities increase the motivation to participate in general and with regard to individual characteristics. Along the same lines, fully-fledged experiments on changes in attitudes, career aspirations or self-efficacy expectations are lacking, too. However, since our examination of publications on making indicated an exponential growth, it is to be expected that there will be further publications dealing with these topics as well.

6.2 Limitations

Our choice of a definition of making aimed at covering the most prototypical maker activities. However, up to now, no definitive definition of the term "making" has emerged. This lack of consensus is evident in both research and practice and thus poses a challenge to provide an overarching literature review. Future meta-analyses based on this scoping review may focus on a larger number of different activities, including weaving or tinkering, that are less related to the digital dimension. Such an even broader review could benefit from the use of Big Data methods which offer great potential to explore the literature in increased depth, including all kinds of work that only implicitly refer to the maker movement. These methods furthermore allow for larger datasets to be screened, which is especially helpful if future reviews should go beyond Scopus as one of the largest available literature databases or beyond focusing on articles written in English (Christ et al., 2019).

Furthermore, although the flexibility of a thematic analysis has been very beneficial for our application purpose, it also entails some disadvantages. Issues such as inconsistency and lack of coherence are often raised as common problems (Holloway & Todres, 2003). Since this can occur, it is necessary to examine the data with a certain focus. We chose digital empowerment as the focus and analyzed the topics in light of their relevance for digital empowerment processes.

Finally, since scoping reviews refrain from excluding studies with low evidence, some authors doubt the usefulness of this method for practical purposes (Daudt et al., 2013). We believe, however, that especially when it comes to emerging research fields, it is important to include studies with weak evidence instead of disregarding them. This is the only way to complete the descriptive-correlational-experimental loop. Additionally, we counteracted this issue by assessing the quality of the included publications in total and therefore offered an overall impression of the quality.

7. Conclusion

Even at the beginning of the third decade after the first FabLab opened, research and practice regarding participation in and design of maker activities are still in their infancy. Yet, the potential for digital empowerment processes is evident. Making in non-formal settings may provide children and youth – especially girls and children from marginalized communities – with equal opportunities to foster their interest in technology and science and build a broad range of competencies. As, however, practitioners may certainly not wait until results from several experiments are available for every issue related to making, scoping reviews like the present one may provide both a starting point for such research and a first glance on the available insights from extant qualitaitve and quantitative research on digital making.

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Data Availability Statement

The data that support the findings of this study are openly available in osf.io at https://osf.io/7dejm/.