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ESD ‹in the Making›?

Potentials and Limitations of Educational Making for Education for Sustainable Development

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Abstract

The article explores potentials and limitations of educational making for education for sustainable development (ESD) based on a list of competencies proposed by ESD researchers to achieve transformational educational goals (Rieckmann 2021). It focuses on three areas offering potential for ESD: first, learner empowerment; second, sustainability thinking, innovation thinking, and entrepreneurship education; and third, Education 4.0 and twenty-first century skills. It outlines central demands and concepts of both ESD and educational making as the theoretical backdrop for the analysis. After presenting core ideas and relevant research in each of the three areas, the article discusses their potential to foster the set of competencies proposed by the ESD movement. The analysis suggests that educational making indeed offers potential for ESD, but with some limitations and conditions that are discussed along with desiderata for further research.

BNE ‹in the Making›? Potenziale und Grenzen von Educational Making für Bildung für Nachhaltige Entwicklung

Zusammenfassung

Der Beitrag untersucht die Potenziale und Grenzen des Educational Making für Bildung für nachhaltige Entwicklung (BNE) auf der Grundlage einer Reihe von Kompetenzen, die von BNE-Forschern vorgeschlagen wurden, um transformative Bildungsziele zu erreichen (Rieckmann 2021). Es werden drei Bereiche fokussiert, die Potenziale für BNE bieten: erstens das Empowerment von Lernenden, zweitens Nachhaltigkeitsdenken, Innovationsdenken und unternehmerische Bildung und drittens Bildung 4.0 und sogenannte 21st Century Skills. Als theoretischer Hintergrund für die Analyse werden zentrale Forderungen und Konzepte sowohl der BNE als auch der Bildungsarbeit skizziert. Nach der Vorstellung von Kernideen und relevanter Forschung in jedem der drei Bereiche, diskutiert der Artikel deren Potenzial, die von der BNE-Bewegung vorgeschlagenen Kompetenzen zu fördern. Die Analyse deutet darauf hin, dass Educational Making tatsächlich Potenziale für BNE

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bietet, jedoch mit einigen Einschränkungen und Bedingungen, die zusammen mit Desideraten für weitere Forschung diskutiert werden.

1. Introduction

In the face of growing global crises – the climate crisis at the forefront – calls for holistic approaches and immediate action are becoming louder and more urgent. Organizations, institutions, businesses, and individuals find themselves under mounting pressure to act sustainably and do their part to protect the planet and its resources. Global efforts to achieve sustainability are not new: The first global climate conference took place in 1992 (BMZ 2023) and the 2030 Agenda for Sustainable Development was adopted by the UN in 2015 as a comprehensive and ambitious «blueprint for peace and prosperity for people and the planet, now and into the future» (United Nations 2023a, history section). Yet these efforts have still not yielded the envisaged results. The 17 sustainable development goals (SDGs) at the heart of the UN agenda are the outcome of decades of global efforts in all areas relevant to ensuring a more sustainable future for humankind. These goals not only address environmental and ecological issues but are also meant as a holistic approach to sustainability that takes social and economic factors into account as well.

Education plays a central role in the SDGs: It is considered not only a human right, but also a «key enabler for sustainable development» (United Nations 2023a, history section). The fourth SDG focuses on education and aims to «ensure inclusive and equitable quality education and promote life-long learning opportunities for all» (Council of Europe 2023, SDG 4), and also includes a set of associated subtargets. In addition, the UN has clearly expressed the «need to integrate sustainable development into formal education at all levels» (United Nations 2023b, education section).

Goals and efforts to incorporate the SDGs into education are concentrated in the education for sustainable development (ESD) concept. At its core lies the endeavor to enable individuals to participate in the processes relevant in shaping sustainable development. This requires the development of certain key competencies and a set of core values around sustainability that need to be embedded in an «action-oriented, transformative didactical approach» (Rieckmann 2021, 10).

An educational phenomenon that has garnered much attention in recent years is *educational making*. Based on the theoretical work of Dewey, Piaget, and Montessori, as well as ideas central to the so-called maker movement, approaches to educational making have gained ground in formal and informal educational settings. Incorporating the use of various activities and tools for *making*, with a focus

on technology in particular, this type of learning has been recognized for its potential in STEM (science, technology, engineering, and mathematics) education (Hsu, Baldwin, and Ching 2017).

The skills and competencies associated with educational making are by no means limited to the STEM field. Meißner (2020) has pointed out the potential of making as a «democratizing culture» and has hailed it as a form of «individual self-empowerment» (Meißner 2020, 6). When engaging in making, the learner assumes the role of designer and engineer in addition to that of the consumer, while using technologies and tools to create something and solve real problems in the process, often in cooperation with others (Meißner 2020). Other authors have discussed educational making in connection with the promotion of sustainability thinking and innovation thinking in relation to entrepreneurship education (Kinnula, Durall, and Haukipuro 2022), as well as Education 4.0 and twenty-first century skills (González-Pérez and Ramírez-Montoya 2022). These aspects provide reasons to believe that educational making can and should be developed and utilized for ESD.

But what concrete potentials does educational making hold for achieving the goals of ESD? While educational making undoubtedly holds promise, especially for STEM education, how and to what extent can it contribute to realizing the «action-oriented, transformative didactical approach» (Rieckmann 2021, 10) ESD demands? This paper aims to answer to this question. In the following section, we consider the two theoretical concepts central to this discussion by exploring and critically examining the aspects of empowerment; sustainability thinking, innovation thinking, and entrepreneurship education; and Education 4.0 and twenty-first century skills for their potential in promoting ESD, taking related research as a point of departure. As literature on educational making in direct relation to ESD is still very scarce, we consider aspects related to or overlapping with goals and competencies of ESD. Due to the explorative nature of this article, we consider all types of making and educational making. The examples presented are not limited to a particular learning setting or age group, in line with the understanding of ESD as lifelong learning. The fourth section explores the limitations of these potentials and offers suggestions for further research. The final section provides a conclusion and discussion aimed at providing a balanced perspective on the issue informed by the article's findings.

2. Theoretical considerations

To determine the extent to which educational making can contribute to education for sustainable development, it is necessary to understand both concepts and their core ideas, principles, and goals. In the first subsection, we present key aspects of ESD and the competencies and approaches associated with it. In the second subsection, we offer a theoretical exploration of the maker movement and educational making.

2.1 Education for sustainable development

As mentioned in the introductory section, education plays a central role in achieving the SDGs. ESD unites all the goals and efforts outlined in the fourth SDG. On the UNESCO website that lays out the trajectory for the implementation of ESD, its general goal is described as giving «learners of all ages the knowledge, skills, values and agency to address interconnected global challenges including climate change, loss of biodiversity, unsustainable use of resources, and inequality» (UNESCO 2023, «What is education for sustainable development?» section). Moreover, it defines the goal of enabling learners to «make informed decisions» so they can participate individually and collectively in global efforts at societal and environmental change toward sustainability. Learning is understood as a lifelong process, and ESD seeks to bring about progress in three domains: the cognitive, the socio-emotional, and the behavioral.

To achieve this progress, educational research has identified key competencies from which educational goals can be derived. The guiding principle is not simply to educate individuals to conform to sustainable behavior and thus to limit their actions; rather, it is to provide individuals with a range of competencies that open up broader options and enable them to find solutions that are tailored to their individual problems (Rieckmann 2021). Rieckmann (2021) identifies eight key competencies that predominate in the international ESD discourse:

- networked thinking competency: the ability to identify and understand relations and contexts, to analyze complex systems, and to understand how systems are embedded within different domains and scales, which involves coping with insecurity
- anticipatory thinking competency: the ability to anticipate and evaluate multiple possible futures and create one's own visions for the future, which involves being proactive and understanding the consequences of actions and managing risks and changes
- normative competency: the ability to understand and reflect on norms and values underlying one's own actions and to negotiate sustainability values, principles, and goals in the context of conflicts of interest and trade-offs, insecure knowledge, and contradictions
- strategic competency: the ability to individually and collectively develop and implement innovative measures that support sustainability on a local and global level
- cooperative competency: the ability to learn from others, to understand and respect others' perspectives (empathy), and to understand, build relationships with, and care for others (empathetic leadership), which involves coping with conflicts within a group to enable collaborative and participatory solution-finding processes

- critical thinking competency: the ability to question norms, practices, and opinions, reflect on one's own values, perceptions, and actions, and to position oneself within the discourse on sustainability
- self-competency: the ability to reflect on one's role in the local and global community, to continually evaluate one's own actions, and keep motivating oneself, to confront one's own feelings and desires
- integrated problem-solving competency: the general ability to apply different solution frameworks to complex sustainability issues and develop suitable, inclusive, and just solutions that support sustainable development and integrate the aforementioned competencies.

Along with these competencies, UNESCO has identified concrete learning goals specific to the aforementioned cognitive, socio-emotional, and behavioral domains. These suggested topics as well as methods and approaches around each of the SDGs can be applied to all types of learning settings and to learners of all ages and backgrounds (Rieckmann 2018).

For learners to develop these competencies, educators and institutions must adopt a transformative approach to education. Rieckmann (2021) emphasizes that these competencies and values cannot simply be transferred to learners but must be developed gradually. As to didactic approaches, the following principles have been identified as appropriate to the transformative, action-oriented pedagogy in question:

- learner-centeredness and accessibility
- focus on action and reflection
- transformative and transgressive learning
- participatory focus
- discovery learning
- networked learning
- vision focus
- integration of social, self-directed, and method-oriented learning with content-oriented learning.

The theoretical work summarized above makes clear that the principles of ESD and the demands it places on educational institutions and actors have been formulated comprehensively and clearly. Educational making, as one possible response to these demands, is outlined in the following section.

2.2 The maker movement

Educational making in its various forms originates from the so-called maker movement, which centers around the activities, principles, and mindsets involved in *making*. Making itself describes the process of experimenting with a variety of different activities, such as «cooking, sewing, welding, robotics, painting, printing, and building» (Hsu, Baldwin, and Ching 2017, 589), and the tools used to create objects or products. Martin (2015) offers the following comprehensive working definition of making as «a class 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, 2).

This takes place in so-called makerspaces or fablabs (fabrication laboratories), open spaces equipped with a range of tools and technologies such as sewing machines, 3D-printers, and workbenches where makers can meet and learn from each other as a community of practice. However, the movement comprises of more than tools and settings; certain values and mindsets also play a central role in it. The «Maker Movement Manifesto» written by Mark Hatch, the founder of one of the first makerspaces, is often quoted in the literature. It differentiates nine core mindsets and activities of making: «make, share, give, learn, tool up, play, participate, support, and change» (Hatch 2014, 1).

In the broader discussion, making has also been associated with certain political and cultural viewpoints and movements. Halverson and Sheridan (2014) mention the «democratizing nature of making» (497) that allows more and more people to use tools and technology to realize their creative ideas and leverage innovative potential regardless of socio-economic status. Making also has notable parallels to hacking that are evident in the mindset at the heart of both communities: tech-enthusiasm, self-actualization, and collaboration. Furthermore, the maker movement is associated with post-capitalist upcycling and repair movements and the idea of modifying, fixing up, and recycling discarded or broken objects to reduce waste and counter consumerism (Bettinger 2018).

2.3 Making and education

While the maker movement initially arose outside formal educational spheres, more and more educators have recognized its potential for learning in K-12 and higher education settings. Eagerness to introduce making into these formal learning contexts has been growing, especially in relation to STEM (science, technology, engineering, mathematics) education. A recently published policy report funded by the European Commission attributes an increasingly important role to educational making in formal education settings (Vuorikari, Ferrari, and Punie 2019). While the

potentials of STEM education are evident, research efforts into making and education have shown that they are not limited to the STEM fields or even to STEM subject content. Hughes and Kumpulainen (2021), for example, argue that making in education can contribute to the development of a host of global skills, such as «creativity, digital literacy, critical thinking, collaboration, and communication» (Hughes and Kumpulainen 2021, 1).

In light of the challenges institutions and individuals face with the rise of digitalization and mediatization (Hepp and Krotz 2012), educational making has garnered the attention of researchers, particularly in media education. Action-oriented media education, for example, seeks to equip individuals with the necessary competencies not only to safely navigate the complexity arising from accelerating technological and societal developments (Stalder 2016) but also to become agents of and (creatively) participate in these processes (Schorb 2022). In one example of recent research in this area, Bunke-Emden (2020) identifies the potential of educational making: by engaging in making activities, individuals can achieve competence in their understanding and adoption of technologies and (digital) media, thereby increasing their capacity to navigate, utilize, and shape these technologies. Other authors in the field have shed light on further aspects and potentials of educational making. Meißner (2022) uses the concept of *maker literacy* to describe the capacity to navigate complexity, whereas Knaus and Schmidt (2020) highlight the potential of making activities to promote the capacity for productive technological action.

Concerning the theoretical foundation of making and education, Martin (2015) and others argue that the notion of making is rooted in longstanding discussion of ideas and theoretical approaches. Martinez and Stager (2013) as referenced by Halverson and Sheridan (2014) credit Seymour Papert's theory of constructionism as the foundational approach for the maker movement and its «focus on problem solving and digital and physical fabrication» (Halverson and Sheridan 2014, 497). Constructionism strongly emphasizes the role of «embodied, production-based experiences» (Halverson and Sheridan 2014, 497) and sees them at the core of any learning process. Constructionism itself is grounded in John Dewey's theory of constructivism. According to constructivist theory, learning happens through play, experimentation, and «authentic inquiry» (Halverson and Sheridan 2014, 479). Learning through making is promoted through approaches like project-based science and problem-based learning. Halverson and Sheridan (2014) and other authors emphasize how making relates to formal and informal educational settings: «Learning through making reaches across the divide between formal and informal learning, pushing us to think more expansively about where and how learning happens» (Halverson and Sheridan 2014, 479).

In addition to the aforementioned aspects, Martin (2015) also refers to four core aspects of the making mindset that are beneficial and can potentially be leveraged for learning:

- Playfulness: enjoyment, pleasure, and fun are central to making and are considered key to intrinsic motivation, which is assumed to be beneficial for educational processes and endeavors. Experimentation and the experience of variation are considered necessary for the development of adaptive expertise and conceptual knowledge (Hatano and Inagaki 1986).
- Asset and growth orientation: Within the maker movement, the idea that anyone can learn the necessary skills to engage in making is prevalent. The focus, according to Martin (2015), is less on abilities or weaknesses, and more on assets and possibilities. Moreover, studies have shown that a growth mindset in learners helps them to cope with failure. The combination of a focus on assets, a growth mindset, and freedom associated with making appears promising for educational settings.
- Failure positivity: The maker movement views failure not as detrimental to the learning process, but as a requirement for learning and improving. This aligns with findings on how to make failure productive in school settings and is associated with developing adaptive expertise (Chi 2011; Martin and Schwartz 2009).
- Collaboration: Sharing and helping are core ideas in the maker mindset and are evident in the formation of large online communities of practice around making. This type of collaboration and communication, focused on «enacted knowledge and non-competitive discourse» (Martin 2015, 7), distinguishes the making mindset in education from more conventional approaches.

3. The potentials of educational making for ESD

The above aspects illustrate the theoretical underpinnings and many potentials of making for educational contexts and purposes. The following sections home in on the question of how three areas of potential in educational making, namely empowerment, sustainability thinking and innovation thinking, and twenty-first century skills and Education 4.0 can contribute to the goals of ESD.

3.1 Empowerment

Several authors have discussed making as a post-capitalist counterculture with parallels to hacking, in that it enables individuals to use existing technologies and design principles to meet their own needs and thus, in a sense, to defy the existing power imbalance between large corporations and the individual (Bettinger, Draheim, and Weinrebe 2020). Illustrative of this type of «individual self-empowerment» (Meißner

2020, 6, author's translation) is the common use of 3D-printers to construct and produce self-designed objects, or the act of de- and re-constructing existing objects. Makerspaces provide individuals with the means to engage in this act of self-empowerment, and the maker culture emphasizes individual enablement through learning and collaboration. This emphasis stands in stark contrast to the simple provision of a service, perpetuating the status quo of individual dependency on corporations or manufacturers to develop technologies. This mindset is evident in a passage from an interview that took place as part of a 2019 ethnographic study referenced by Bettinger, Draheim, and Weinrebe (2020). In it, the interviewee describes his rationale for teaching individuals how to repair things themselves and showing them «how-to» instead of seeking out service providers. He refers to this as «demystification of the machine» (Bettinger, Draheim, and Weinrebe 2020, 23, author's translation). He sees it as important for the future that individuals be provided with the means to escape from being passive victims of digitalization and assume agency by becoming co-creators.

The foregoing examples reveal the potential of individual empowerment to counter consumerism and dependency through making. But how can this potential empowerment be realized in education and particularly ESD? Clapp et al. (2016) discuss maker empowerment and education within the context of human agency. This concept can be linked to fundamental questions about «the nature of intention and action, the possibility of free will and autonomy, issues of ethics and moral responsibility, explanations of rationality and akrasia (weakness of will), theories of human motivation, theories of economic behavior, and theories of human rights» (Clapp et al. 2016, Chapter 4, «What is Agency» section[1]). As the result of an attempt to synthesize the outcome of a long tradition of researching and contemplating human agency in the fields of philosophy and psychology, they offer a loose definition of agency as «our species' capacity to make intentional choices about how to act in the world (Clapp et al. 2016, Chapter 4, «Choice, Intention and Action» section).

They define *maker empowerment*, understood as agency in relation to making, as «a sensitivity to the designed dimension of objects and systems, along with the inclination and capacity to shape one's world through building, tinkering, re/designing, or hacking» (Clapp et al. 2016, Chapter 4, «Agency and Maker empowerment» section). They regard agency in the context of making as a specific underlying disposition that lifts individuals out of a type of paralysis (maker *un*empowerment) resulting from ignorance toward the design and production processes involved in shaping our material world. The authors see maker empowerment as a central, broad outcome of maker-centered education and envision that learners who are maker-empowered will adopt strategies to design, construct, improve and re-think the material and immaterial world around them.

1 Source only available in eBook format without page numbers.

They identify three key notions that are central to their notion of maker empowerment: a «sensitivity to the designed dimension of objects and systems» (Clapp et al. 2016, Chapter 4, «Empowerment in education» section), meaning alerting learners to the ways our world is filled with things of human design, and the «inclination and the capacity to make (or remake) things» (ibid.), relating to both the required motivation and the necessary skill set. These notions that comprise the disposition of maker empowerment could relate to competencies in ESD, particularly strategic competency, self-competency, and, most of all, critical thinking competency, as defined in the second section of this paper.

This assumption is supported by the discussions and contributions around *critical making*. Grimme, Bardzell, and Bardzell (2014) view empowerment as «a motivation and reward» (Grimme, Bardzell, and Bardzell 2014, 432) for critical making, which they define as «making activities in which the practice of making itself is a vehicle for critical engagement with the world, as opposed to making something purely for its material benefits» (Grimme, Bardzell, and Bardzell 2014, 431). The rationale employed here is that making can lead to a critical view of the world, while the focus is more on the act of making as an activity than on the resulting product. From the results of their qualitative study, the authors identified three types of empowerment, further explaining aspects of empowerment associated with making:

- Empowering oneself: artifacts and activities that allow makers to reject a passive consumerist subject position and assert themselves as agents of their own infrastructural and/or device ecologies.
- Empowering others: artifacts and activities that allow makers to teach and inspire others, to raise awareness or affect changes around social issues, or to create new choices for artifacts or experiences.
- Empowering making communities: artifacts and activities that allow makers to contribute to the making community by sharing tools, resources, networking, and collaboration (Grimme, Bardzell, and Bardzell 2014, 434).

This analysis would add cooperative competency to the list of competencies as defined by ESD. Moreover, it has become evident that the different aspects of empowerment laid out above could contribute to the attitudes necessary for ESD. In later sections, we present a critical examination and limitations of this study, especially regarding the following two potentials.

3.2 Sustainability thinking, innovation thinking, and entrepreneurship education

The second potential of educational making for ESD displays some links to empowerment, but is centered around the domains of technology, design, innovation, and entrepreneurship in learners and their importance for ESD. Kinnula, Durall, and

Haukipuro (2022) note that, «the role of innovation in solving global challenges such as climate change and sustainable development is becoming increasingly important» («Sustainable innovations require sustainability thinking» section[2]). Efforts at leveraging the potentials of innovation and entrepreneurship for sustainable development are subsumed under the concept of *sustainable innovation,* which refers to «seeking solutions to complex issues, bringing a competitive advantage for companies but also providing environmental benefits and producing social well-being» («Sustainable innovations require sustainability thinking section»).

In emphasizing the importance of innovation for sustainable development, Kinnula, Durall, and Haukipuro (2022) note the significance of the role of learners as «agents of change» («Sustainable innovations require sustainability thinking section») as well as «design protagonists» (Introduction) meaning that they not only have the necessary competencies to develop new technologies but can also reflect critically on existing technology and its role in their lives and the lives of people around them. According to the authors, sustainability thinking and innovation thinking are key building blocks for entrepreneurship and innovation education, which is important in developing skills, such as sustainability literacy, that enable learners to engage in innovation and entrepreneurship toward sustainable development. The authors also comment on the importance of inter- and transdisciplinary thinking, which stems from the «intrinsic complexity of sustainability challenges» (Kinnula, Durall, and Haukipuro 2022, «Sustainable innovations require sustainability thinking» section). They assign making to the realm of learning approaches that foster these necessary competencies and dispositions in learners. According to the authors, educational making approaches support «learners' engagement in sustainable thinking through activities involving design and technology» (Kinnula, Durall, and Haukipuro 2022, «Sustainable innovations require sustainability thinking» section), and they propose that the principles of educational making be linked with sustainability education and design thinking.

This research yields insights into the importance of linking systems thinking with sustainable innovation and incorporating both into design and entrepreneurship education. Kinnula, Durall, and Haukipuro (2022) propose an approach that uses business ideating and business idea development in connection with sustainability education couched in maker approaches as a way to teach systems thinking, a key skill necessary to avoid shallow solutions and instead develop holistic approaches to problems. This approach aligns with the ESD competencies of networked, anticipatory, and strategic thinking, as well as integrated problem-solving competencies. Fostering sustainability thinking, innovation thinking, as well as systems thinking alongside an entrepreneurship mindset to enable learners to become

2 no page numbers provided in source.

design protagonists appears to contribute in multiple ways to the development of ESD competencies. In the following, we present further research that lends weight to individual aspects of the approach of Kinnula, Durall, and Haukipuro (2022).

The approach of linking entrepreneurship education and making to promote entrepreneurship with a focus on learner creativity finds support in a study by Weng, Chiu, and Tsang (2022). They employed a 5E (engage, explore, explain, elaborate, and evaluate) learning cycle around a five-month maker program using 3D-printers to glean insights into how creativity and entrepreneurship are affected by engaging learners in making activities involving real-world problems. They found that learners displayed a «novelty dimension of creativity» (Weng, Chiu, and Tsang 2022, 11) in the engage phase, and entrepreneurship in multiple phases of the 5E cycle as evaluated using two frameworks. These findings arguably contribute to the assumption that making, especially when embedded within instructional design frameworks such as the 5E cycle and linked to real-world problems, can promote entrepreneurship and creativity, key skills for the competency cluster.

Another approach proposed in 2017 and researched over three years as in the «DOIT – Entrepreneurial skills for young social innovators in an open digital world» European research and innovation program employs different types of makerspaces and tools to promote «practice-based social innovation and entrepreneurial learning of children and young people» (Geser et al. 2019, 60). Although one of the program's focal areas was entrepreneurship education, it aimed more at developing the mindset and skills necessary to derive entrepreneurial action from creative ideas rather than following a commercial approach to entrepreneurship (Unterfrauner, Voigt, and Hofer 2021). The topics addressed in the learning program range from social inclusion to political involvement to resource efficiency, and thereby appear to align to some degree with the SDGs and ESD, in addition to addressing real-world issues. Moreover, the pilot projects described by the researchers aim at ensuring participation for groups that are typically underrepresented in makerspaces, such as girls and children with disabilities. The researchers report positive results and see value in linking making and entrepreneurship education to foster competencies for social innovation (Geser et al. 2019).

In a subsequent article, Unterfrauner, Voigt, and Hofer (2021) narrowed their focus to two key aspects and evaluated the development of non-cognitive skills of the aforementioned piloted learning program along the dimensions of *creativity* and *self-efficacy*, which are at the heart of entrepreneurship education. The authors used a standardized psychological test to measure creativity and selected the most suitable items from several standardized scales for measuring self-efficacy, establishing the reliability of their instrument using Cronbach's alpha. They found a significant increase in creativity and self-efficacy in the posttests as compared to the pretests. Moreover, they found positive effects in all countries and institutions participating

in the DOIT program, showing that the maker educational approach employed contributed significantly to the development of those non-cognitive skills that are most relevant for entrepreneurship education: creativity and self-efficacy. These results lend weight to the assumption that educational making, embedded within a learning program such as DOIT, can indeed foster entrepreneurial skills such as creativity that are necessary for social innovation and that can potentially contribute to ESD.

3.3 Education 4.0 and twenty-first century skills

In their 2022 review, González-Pérez and Ramírez-Montoya link twenty-first century skills and computational thinking to ESD in saying that «twenty-first century skills, knowledge, and attitudes are necessary for citizens to face the digital, sustainable, and social world ethically and humanistically» (González-Pérez and Ramírez-Montoya 2022, 5). From their review, it is evident that twenty-first century skills, alongside transversal competencies such as computational thinking, go hand in hand with the goals of ESD, and that most of the competencies contained in the frameworks calibrating twenty-first century skills are largely identical with those defined in the ESD framework. In the following, two research efforts are presented that examine the role of maker education in fostering twenty-first century skills, albeit referring to differing frameworks.

Iwata et al. (2020) explore how digital fabrication activities as a part of maker education can contribute to the development of «non-subject transversal competencies» (Iwata et al. 2020, 2). These are a set of values, skills, knowledge, attitudes, and motivation that can be applied to problems across disciplines and situations and are incorporated into the Finnish core curriculum for basic education. The authors focus on two transversal competencies – twenty-first century skills and computational thinking – and explore the potentials of maker education in contributing to their development. They refer to twenty-first century skills as described in a set of competencies and attitudes comprised of «ways of thinking», «ways of working», «tools for working» and «ways of living in the world», categories defined in a project called ATC21S (Assessment and Teaching of Twenty-First Century Skills). The subcategories of competencies within these four major categories include critical thinking, innovation, creativity, collaboration, and ICT skills. Most of these skills align with the competencies defined as aims of ESD.

Computational thinking, on the other hand, «refers to a way of solving complex problems by applying the set of thinking skills, practices and approaches which are fundamental to computing» (Iwata et al. 2020, 3). The idea is based on two concepts that are fundamental to computing: abstraction and automation. At the core of the approach of integrating computational thinking into education is the idea that it will enable learners to better comprehend the ways computers and technology function

and use them for their own ends. Also, it involves problem-solving approaches that can be applied to situations beyond working with ICT. As a transversal competency, computational thinking is seen as an integral part of Education 4.0, which is defined as education responding to the needs created by the fourth industrial revolution. This, in turn, is characterized by «disruptive technologies, processes, and practices» (González-Pérez and Ramírez-Montoya 2022, 2).

The research of Iwata et al. (2020) culminated in the finding that creativity as a twenty-first century skill was enhanced in learners, leading them to engage «in the creative fabrication process with freedom and autonomy of ideation and designing» (Iwata et al. 2020, 7). Other twenty-first century skills that could be improved through work with digital fabrication were «problem solving, critical thinking and decision making» (Iwata et al. 2020, 7). Moreover, they found opportunities for learners to develop collaboration, communication, and ICT skills, as well as a change in attitude regarding citizenship and communal focus. Concerning the development of computational thinking, it was found that learners frequently employed several of the steps in computational thinking, such as «formulating problems in a way that computer and other tools can help solve them» (Barr et al. 2011, 21). The researchers conclude that «digital fabrication activities have the potential for learning of the skills covering all four categories of twenty-first century skills and several aspects of CT practices» (Iwata et al. 2020, 12).

Striukova and Rayna (2019) focus on twenty-first century skills, elaborating both the reasons for their importance and certain issues they raise. For instance, the authors note that twenty-first century skills are important in maintaining employability in an increasingly digitized labor market. At the same time, however, some «are hard to foster in a traditional classroom environment» (Striukova and Rayna 2019, 1). Moreover, the authors state that although twenty-first century skills are a requirement to participate in the labor market, they are difficult to attain for individuals outside «the part of the population that typically has access to higher and further education» (Striukova and Rayna 2019, 1). They discuss the growing digitization of the physical world, which brings with it an increased requirement to learn new skills, but also presents new possibilities for entrepreneurship, while the needed skills are by no means limited to the STEM field. Linking these findings to educational making, the authors pose the question of the role of maker education, in particular fablabs, in fostering these twenty-first century skills. In their research, they refer to two frameworks, the DigComp and EntreComp frameworks proposed by the European Commission, which they combine into one overarching framework for twenty-first century skills. The DigComp framework comprises a list of competencies related to digital and information technologies deemed essential for the twenty-first century. The EntreComp framework relates to entrepreneurship in terms of a set of competencies and encompasses more non-cognitive skills, many of which are

analogous to the competencies defined in the ESD framework. The researchers conducted a two-stage qualitative study (interviews and focus groups) with members of fablabs, some of which had an explicit focus on entrepreneurship education, while others did not. Their research showed that the following twenty-first century skills were organically fostered through activities in the fablabs, regardless of their entrepreneurial focus: creativity; the ability to mobilize resources; the ability to cope with uncertainty, ambiguity, and risk; the ability to work with others; and the ability to learn through experience. Moreover, the following twenty-first century skills are likely to be fostered organically in fablabs: the ability to mobilize others and take the initiative; to a lesser extent, self-awareness and efficacy; motivation, and perseverance; and finally, planning and management. Other skills were fostered in the fablabs that did indeed have an entrepreneurial focus. Interestingly, the skill of ethical and sustainable thinking was fostered only in those fablabs that emphasized related issues in the activities they offered.

4. Limitations and suggestions for further research

While the aspects of educational making presented above show great potential for the development of certain competencies defined in ESD, there are, of course, limitations to the scope and impact of educational making on ESD. Also, as hinted at above, the effect of their contribution to ESD may hinge on certain conditions. Furthermore, it is important to address some aspects of educational making and the maker movement that are misaligned with the idea of sustainability and the SDGs in general. In the following, we discuss the most pressing limitations of educational making approaches, further considerations, and the resulting research desiderata.

A first limitation to be addressed and perhaps the most obvious is inherent in all endeavors that aim to contribute to ESD, namely the fact that no single action or change will have the impact required for the transformation needed to achieve the SDGs. Rieckmann (2021) speaks of the «transformative didactics» (Rieckmann 2021, Fazit section) required to achieve the major changes on all levels of society and, in turn, achieve the SDGs. Educational making in any form can only be one piece of the puzzle, and is no panacea or «silver bullet» (Martin 2015, 8) to resolve the deep-rooted problems of traditional education. Moreover, research into educational making and sustainability and ESD is still in its infancy. The few approaches mentioned in this paper hardly form a solid base for argumentation and should only be viewed as a first point of orientation. Only a few of the articles directly mention educational making in combination with ESD or sustainability. It can therefore be stated that further research is needed on all topics relating to both fields. A systematic literature review or mapping review to determine the current state of research could be a first starting point to identify further steps.

Moreover, it seems that making in general is by all accounts a very heterogenous concept that displays wide variations in form. Each makerspace, hackerspace, or fablab is different, from its equipment to its members, community, and internal organization to its mindsets, individual practices, and focuses. This will without doubt influence the competencies that are fostered within each makerspace or fablab. This was evident in the research of Striukova and Rayna (2019), where a focus on entrepreneurship in some makerspaces affected the competencies acquired. This also poses challenges for schools, other educational institutions, individuals, and groups considering creating a maker infrastructure to enhance formal or informal education. As Blikstein (2018) states: «It is challenging to choose between the models and know, in each case, how to build the spaces, train teachers, manage labs, and incorporate the particular maker practices pertaining to each model» (Blikstein 2018, 431). More research, it seems, should go into developing ways of identifying and assessing needs, requirements, and options for educational institutions and support them in introducing an adequate form of educational making into their infrastructure. Moreover, the training of educators as key facilitators of educational making in formal education requires further research.

On this point, the success and possible impacts of educational making, especially with regard to ESD, hinge on a variety of contextual factors and conditions. Martin (2015) argues that three critical elements are necessary in order to realize the full potential of making in education: digital tools for making, the community infrastructure, and the maker mindset. Martin warns of a «tool-centric approach» (Martin 2015, 8) to introducing making into education that involves a tendency to oversimplify, which will ultimately result in failure. It may seem obvious, but simply creating a physical makerspace in a school or higher education setting will not necessarily result in the development of the desired competencies. Further research could look into ways of introducing the three elements mentioned by Martin (2015) into educational settings and examine their interplay within these settings, focusing on the desired and achieved outcomes. A related question is how educational making should be embedded within educational frameworks, as studied in the research by Geser et al. (2019) and Weng, Chiu, and Sang (2022), and how this affects the implementation of maker education and its outcomes.

Another critical aspect is illustrated by Blikstein (2013), who reports what he calls the «keychain syndrome» (Blikstein 2013, 8,) and warns of trivialization and valuing «‹product› over ‹process›» (Blikstein 2013, 9) in educational making activities. This, he states, is a symptom of an incentive system deeply ingrained in traditional education. In the vignette he describes, it resulted in learners making one keychain after another using a laser cutter. It became evident that the maker mindset was lacking, resulting in the learners «mass-producing» (Blikstein 2013, 9)

a product instead of experimenting, ideating, and problem-solving. This can hardly be aligned with the goals of ESD, much less with the general idea of sustainability, and poses a real issue for the introduction of maker infrastructures into education.

Another related issue, which also shows the interrelatedness of the three potentials discussed in this paper, may pose a limitation to the potential forms of empowerment offered by educational making. It lies in potentially conflicting goals of making and relates to the problem of valuing product over process as described by Blikstein (2013). It may be inherent particularly in settings combining maker educational approaches with entrepreneurship education and the fostering twenty-first century skills. Bettinger, Draheim, and Weinrebe (2020) argue that while forms of individual empowerment and liberation from the power imbalances relating to market mechanisms can indeed be achieved through making, there is always a risk of confusing this approach with one that fosters skills only to increase employability, thus surrendering to neoliberal agendas and ideals. This would run counter to the forms of empowerment offered by educational making and appears to highlight an area of conflict, especially between educational making and ESD.

Further, issues the maker movement, educational making, and ultimately, all research on educational making must consider are the boundaries, exclusivity, and underrepresentation of certain groups in making communities and spaces. One of the groups most underrepresented in making infrastructures are women and girls, who often tend to «avoid spaces that they find to be overtly male-dominated» (Capel et al. 2021, 2). This echoes the much lamented but little improved imbalance between men and women, girls and boys in the STEM field, especially in technology and computing (Lewis 2019). Moreover, Bettinger, Draheim, and Weinrebe (2020) found that in the daily practices within the makerspaces they examined, stereotypical gender roles are frequently reproduced, for instance, in the attribution of talents or interests. According to Lewis (2019), this imbalance leads to two problems of wider social relevance, the first being that the potential workforce in STEM related fields is significantly reduced if the number of women in these fields continues to decline. Second, the trend leads to reduced diversity in these fields, «though it is known that diversifying work environments increases the creativity and innovation of industries, thus creating more and better paths to improved output, be that manufacturing, theoretical research and development, or practice» (Lewis 2019, 3). This issue that making seems to have inherited from the STEM field, beyond the problem of passing up valuable opportunities for educational experiences, may place educational making at odds with the SDGs, may put research at risk of being flawed, and could significantly limit the impact of the potentials of educational making for ESD. However, as Bettinger, Draheim, and Weinrebe (2020) found, makerspaces also have

the potential of deconstructing and subverting stereotypical gender roles. Therefore, it should be of paramount concern to future research to identify ways of leveraging makerspaces to alleviate this issue rather than exacerbating it.

The aspects and issues presented above, although far from having been exhaustively discussed, warrant calls for normative guidance in terms of embedding educational making within the wider debate of ESD and normative approaches. All three aspects laid out above may contribute to the development of competencies called for by ESD: networked thinking competence, strategic competence, collaborative competence, or integrated problem-solving competence. Moreover, research presented above suggests that educational making fosters creativity and self-efficacy, as well as transversal skills such as computational thinking. However, any effort at leveraging these potentials, it seems, requires a normative discussion and the development of normative competence in learners as mentioned by Rieckmann (2021) to calibrate efforts at educational making and to render it truly and sustainably fruitful for ESD.

Particularly with regard to the relation of the individual to an increasingly digitized world, the question of individual responsibility for issues of sustainability can and should also be raised (Grünberger 2020). The potentials discussed above all raise questions about this, such as when design and prototyping skills are fostered in educational making settings. An important endeavor will be to explore the potential of educational making, first, to enable individuals to position themselves within the debate on environmental responsibility in an increasingly digitized world and, second, to enable them to assume responsibility by educating them, for instance, on production processes. Grünberger (2020) emphasizes the importance of media education in shaping the necessary educational trajectory and assuming the role of ‹first responder› to developments in this field, to which educational making arguably belongs. Considering the increased permeation of every aspect of human life by digital technology, the resulting contingency (Bettinger and Jörissen 2022), and the implications for education on all levels, educational making can be considered a promising and important area for research in the field of media education. As outlined briefly in the second section of this article, this field already offers approaches to research and practice that could point the way toward further efforts in relation to educational making and ESD.

Pressing questions for further research and theoretical inquiry in this vein could therefore be: How and to what extent can educational making contribute to the development of required normative competencies? What are the conditions for this? Can the playful and experimental nature of making at the heart of educational making approaches be consolidated with the development of certain values and attitudes required to direct the acquired skills toward the achievement of ESD and the SDGs? How can and should educational making be embedded within a wider

discussion of responsibility and sustainability? How can theoretical and empirical approaches in the field of media education, for instance, with regard to action-oriented media education (Schorb 2022), be utilized fruitfully for further inquiry into ESD and educational making, particularly in formal educational settings? To what degree can trajectories and approaches in the field of media education, for example, with regard to *digital agency* (Freund et al. 2023) and other fields of educational research and practice, be aligned with ESD?

5. Conclusion

Educational making, at a first glance, offers a host of exciting and promising advantages and potentials, especially for STEM education but also beyond. The SDGs and particularly the goals defined by ESD demand a transformative approach to education and, since educational making seems to subvert many of the issues of traditional education, it warrants closer examination into its potential role in achieving this transformation. Therefore, looking beyond content-related education, the question raised in this paper was: In what ways and to what extent does educational making hold potential to contribute to ESD?

In the attempt to formulate an answer to this question, three interrelated potentials of educational making were examined in an explorative approach: empowerment; sustainable or innovation thinking and entrepreneurship education; and Education 4.0 and twenty-first century skills. Contributions in the form of didactic approaches, reports, monographs, as well as research articles were studied to determine avenues in the research and gain insights into how and to what extent these potentials relate and contribute to the development of the competencies of ESD. Relating to the question initially posed, the answer would have to be: It's complicated and it depends. It was shown that, while educational making can indeed contribute to the development of certain competencies defined in ESD, such as collaborative competency, strategic competency, networked thinking competency, and integrated problem-solving competency, certain limitations apply that cannot and must not be disregarded. From these limitations, further avenues of research were identified in light of the fact that research on educational making and ESD is still in its very early stages. Moreover, it became evident that making, as a highly heterogenous concept, can be considered a ‹double-edged sword› in certain respects, generating both potentials *and* pitfalls, for instance, by either perpetuating or subverting gender disparities. Above all, the need to negotiate normative underpinnings seems the most pressing issue at hand to calibrate the direction forward with educational making and ESD. An integration of approaches to increased digitization and mediatization – as addressed by research in the field of media education – and ESD could form an especially promising two-pronged research trajectory for the future.

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