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Understanding practicing and assessment of 21st-century skills for learners in makerspaces and FabLabs

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Abstract

Despite the opportunities that makerspaces and FabLabs offer for the development of 21st-century skills, understanding how these skills are being practiced and assessed in these spaces has been proven challenging. In this work, we address this gap through an interview study investigating 13 maker-educators' practices across different makerspaces and FabLabs. The findings reveal that, in general, maker-educators' practice is not guided by any formal 21st century skills framework. Instead, they draw ideas from their national school curricula, literature, and primarily their own experiences and perceived best practices in their contexts. They report evidence of practicing 21st-century skills, most frequently referring to five skills: collaboration, creativity, communication, life/social skills, and problem-solving. Yet, they do not explicitly assess the development of these skills, for reasons that have to do with (i) the practical nature of making, which emphasizes the development of a tangible result and not skills development as such, (ii) the demanding nature of the making activities, which requires a lot of hands-on time, leaving no room for assessment, (iii) the making ethos, which presents maker-educators with choices around what to pursue and how to go about it, and cannot restrict making activities within the boundaries of formal assessment practices. The study helped to document some making practices linked to the practicing of 21st-century skills, as reported by the participating maker-educators. Future work could focus on the design of assessment practices and tools that can help to capture and advance the development of 21st-century skills in maker contexts, while respecting the openness in the making ethos.

Keywords 21st -century skills · Assessment · Makerspaces · FabLabs · Maker education

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1 Introduction

Educational systems worldwide are responsible for equipping today's students with the necessary competences and skills to apply their knowledge in newfound situations and be prepared for their future jobs (Rissanen, 2014). During the past years, numerous educational frameworks for the development of 21st -century skills serve as points of reference to better prepare students to succeed in work and life (P21, 2019; Griffin & Care, 2015). In general, 21st-century skills include citizenship, collaboration, communication, creativity, critical thinking, global awareness, ICT literacy, personal and social responsibility, and problem solving (Bacigalupo et al., 2016; Ferrari, 2013 P21, 2019). Such skills "are transversal, have mobility, adaptability and accessibility across subject matter without being directly linked to a content base" (Kipp et al., 2018, p. 42).

Recent research revealed that some 21st -century skills are difficult to foster in a traditional classroom environment, as they require learners' activity in physical spaces, access to technologies, and multidisciplinary approaches in teaching and learning including hands-on learning (Rayna & Striukova, 2021). Meanwhile, an increasing body of literature reports that makerspaces and FabLabs, as learning spaces, have the potential to foster the development of a range of 21st -century skills (Freiman, 2020; Iwata et al., 2020; Rayna & Striukova, 2021; Koul et al., 2021; Ioannou & Gravel, 2024; Miliou et al., 2023). Some researchers have recently documented the relationship between making and 21st-century learning, looking at how making projects can help students develop the necessary skills to achieve their career and life goals through the identification of their strengths and areas of interest (Freiman, 2020).

Makerspaces and FabLabs are extremely diverse environments (Mersand, 2021) ideal for openness and experimentation. Sheridan et al. (2014) described makerspaces as learning environments that may differ based on the target audience and the level of experience but "*a commonality is that these spaces all involve making: developing an idea and constructing it into some physical or digital form"* (p. 507). Specifically, a makerspace is a hands-on learning environment where learners explore project-based learning, participate in learning-by-doing activities, and develop innovations (Pepper-Kittredge & DeVoe, 2016, Ioannou & Gravel, 2024). FabLabs, although sometimes perceived as synonymous with makerspaces, include sophisticated technology which requires specific equipment, such as 3D printers and fabrication tools (Mersand, 2021). In both makerspace and FabLabs, learners are exposed to non-traditional methods of learning that encourage the development of collaborative and iterative projects which "pave multiple pathways to learning 21st -century skills" (Blikstein et al., 2017), such as creativity, problem-solving, productive participation in teamwork, and flexibility in the use of digital technologies (Häkkinen et al., 2017; Papavlasopoulou et al., 2017; Timotheou & Ioannou, 2021a, b). More recently, makerspaces and FabLabs can be found within school units or campuses, for access to learners and educators as part of formal education. In such spaces, maker-educators might deliver lessons linked to the school curriculum in addition to encouraging learning through experimentation.

Despite the opportunities that makerspaces and FabLabs offer for the development of 21st- century skills, understanding how these skills are incorporated and assessed

in makerspaces has proven challenging. In fact, the literature concerning learning and assessment in such contexts is largely focused on STEM-related outcomes (Martin, 2015; Clapp & Jimenez, 2016). There is little information on how 21st -century skills are incorporated in different activities and projects (Lin et al., 2020), and what types of assessments are most appropriate (Rayna & Striukova, 2021; Miliou et al., 2023). For instance, a survey by Peppler et al., (2017) reported that makerspace practitioners experience several barriers in their assessment practices which include but are not limited to the lack of access to dedicated technology for documentation, lack of youth motivations to capture making, and documentation taking time away from and interrupting the flow of making. Overall, prior studies have already highlighted several challenges concerning assessment in makerspaces and lack of assessment practice. To address this gap, we engaged in an interview study, focusing on the perceptions of experienced maker-educators regarding the practicing and assessment of 21st-century with young learners and adolescent working in makerspaces and FabLabs. Particularly, we sought to answer the following research questions:

RQ1 What kinds of 21st -century skills do learners practice in maker contexts?

RQ2 How do maker-educators engage in the assessment of 21st -century skills in maker practice?

2 Background work

2.1 Maker education, tools, and practices

In the past years, educational institutions have shown increased interest in the maker movement and maker education (Clapp et al., 2016). Maker education is based on the theoretical foundations of constructivism and constructionism. According to Blikstein (2013), Papert's Constructionism builds upon Piaget's Constructivism "which underlines the significance of constructing knowledge particularly well when learners build, make and publicly share objects" (p.5). Learning that is guided by constructionism has its focal point on personal, concrete forms of knowledge, where students are leading their own learning (Papert, 1991). In the context of maker education, constructionism is linked to interdisciplinary learning, which brings together Science, Technology, Engineering, Art, and Math (STEAM) subjects into a process of inventive inquiry (Blikstein, 2013; Gravel et al., 2023; Ioannou & Gravel, 2024). In maker education, learners are given opportunities to engage in making, tinkering, coding and play using different tools and materials (Gravel et al., 2022; Honey, 2013; Martinez & Stager, 2013; Timotheou & Ioannou, 2019a, b). Such activities might include the use of cutting-edge hardware and software (Blikstein, 2013), such as microcontrollers/microprocessors, digital and non-fabrication tools, photography tools, and robotics to enable coding, crafting, and soldering (Martin, 2015; Ioannou & Gravel, 2024). Tools and materials have a dual role in maker education: first, they

support the learning process, and second, they serve as tools for expression when constructing an artefact (Martin, 2015).

Makerspaces and FabLabs vary in their organizational structure. They can be public or private spaces (Rayna & Striukova, 2021) offering infrastructure and enabling knowledge sharing between makers "in a community environment – a library, community center, private organization, or campus" (Educause, 2013, p.1). In such spaces, users typically engage in self-initiated projects developing skills as a non-formal learning experience. More recently, makerspaces and FabLabs can be found within school units or campuses, for access to learners and educators as part of formal education. In such spaces, maker-educators might deliver lessons linked to the school curriculum in addition to encouraging learning through experimentation. In all cases, makerspaces and FabLabs accommodate practices, such as project-based, inquiry-based, interdisciplinary learning, and experiential learning enabling users/learners to develop multifaceted skills through complex design and making practices (Sheridan et al., 2014; Pepper-Kittredge & DeVoe, 2016; Bevan, 2017). Such practices allow learners to engage in hands-on activities that require higher-order thinking, tinkering, exploration, building and constructing to take place simultaneously (Bevan, 2017).

Overall, makerspaces and FabLabs, in formal or informal contexts, can provide powerful contexts for learning (Bevan et al., 2015) where learners explore, tinker, create, make, and remake products that may provide solutions to problems meaningful to them (Iwata et al., 2020). Learners in maker contexts can identify themselves as designers, engineers, or constructors who are engaged in many forms of working, expressing, and building (Blikstein, 2013). Such learning experiences, realized in makerspaces and FabLabs, can foster the development of 21st -century skills (Iwata et al., 2020; Milliou et al., 2023; Ioannou & Gravel, 2024; Rayna & Striukova, 2021).

2.2 21st -century skills in maker education

21st -century skills refer to a set of skills which are considered essential for the successful journey of learners in today's world. Specifically, these skills are said to better prepare students to thrive in today's global economy and achieve their goals (Kay & Greenhill, 2011). During the past decades, various 21st -century skills frameworks have been developed to guide educational policy and practice e.g., Partnership for 21st Century Skills (P21, 2019), DigComp 2.1 framework (Carretero et al., 2017), EntreComp framework (Rayna & Striukova, 2021), Australian Council for Educational Research (ACER) skills development frameworks (Scoular et al., 2020) and more. These frameworks refer to a blend of knowledge, skills, expertise, and literacies that are necessary for learners to succeed in their personal and professional lifework and in life.

Maker education is seen to provide rich opportunities for the use of 21st -century skills (Iwata et al., 2020; Miliou et al., 2023; Rayna & Striukova, 2021). For example, Rayna and Striukova (2021) argued that the half-digital half-physical nature of these learning environments provide opportunities for the development of entrepreneurial and digital skills. Others reported that makerspaces offer appealing environments and technologies for the development of creative skills, problem-solving skills, collaborative and communication skills (Soomro et al., 2022). Similarly, Gruen (2018)

suggested that making activities can nurture communication, problem-solving, and technology skills and enhance self-esteem. Furthermore, Timotheou and Ioannou (2021a, b) documented the presence of creativity and innovation skills, critical thinking and problem-solving skills and communication and collaboration skills during students' engagement with making activities. Others, view makerspaces as environments where social change can flourish (Burke & Crocker, 2020; Milara et al., 2020). Because making, in its essence, consists of exploring through hands-on practices, the process of making acts as a 'social glue' for learners to connect and take part in making activities (Marsh et al., 2017). Lastly, Iwata et al. (2020) perceived makerspaces as potential spaces for the development of computational thinking as a category of 21st -century skills nourished through digital fabrication activities.

Despite the opportunities that learning spaces such as makerspases and FabLabs offer for the development of 21st -century skills, prior studies report challenges in integrating such skills in teaching and learning in formal or non-formal learning settings (Care, 2018; Kipp et al., 2018). There are several reasons why such challenges exist; these skills lack distinction, are not perceived clearly by learners or educators and are therefore, challenging to integrate, practice, and assess (Care, 2018; Nieveen & Plomp, 2018; Schad & Jones, 2020). In maker contexts, such challenges may be even more prominent as the metrics for success are mainly based on student interest, engagement, and excitement (Weiner et al., 2018), rather than measurable skills. Indeed, Peppler et al. (2017) reported that there is a lack of firm answers about how 21st -century skills can be developed and measured in maker contexts. Additionally, integrating 21st -century skills into maker activities is a demanding process which requires educators to identify tool affordances, intended skills, outcomes and assessment methods (Giannakos et al., 2017). A couple of recent studies have focused on designing digital tool for self-assessment and reflection in maker contexts (e.g. Miliou et al., 2023; Kumar, Wardrip, & Millerjohn, 2023). One such effort focuses on the students' use of 21st century skills and reports positive findings concerning students' increased awareness of their development of 21st-century skills during making (Miliou et al., 2023); despite the reported challenges in adopting the self-assessment and reflection tool in their making practice, the study reports positive findings concerning students' increased awareness of their development of 21st-century skills during making. Overall, understanding how these skills are being practiced and assessed in these spaces remains challenging. In this work, we address this gap through an interview study investigating 13 maker-educators' practices across different makerspaces and FabLabs.

3 Methods

In this section, we describe the methods of our interview study–the process of recruiting interviewees and interviewing. We then provide a synopsis of our thematic analysis of the interview data.

3.1 Recruiting interviewees

We followed the purposeful sampling approach (Emmel, 2013) and particularly identified makerspaces with varied characteristics, considering in-school makerspaces vs. out-of-school makerspaces, maker curricula that involves links to the school curricula vs. extracurricular, and the nature of the making projects at the makerspace or FabLab. We recruited educators /facilitators in the selected makerspaces by leveraging existing connections to these makerspaces through a European project and network. The general aim was to explore how these maker-educators incorporate and assess 21st-century skills in their maker practice with young learners and adolescents.

The final list of interviewees included 13 makerspace and FabLab educators (or self-identified as maker facilitators per profession title) coming from four European countries; 9 were females, and 4 were males. Five ($n=5$) of them were maker-educators working in makerspaces within primary and secondary public schools and implementing making activities as part of the formal educational curriculum. The rest ($n=8$) were maker-educators working in public or private makerspaces or FabLabs as an extracurricular activity (i.e., non-formal education). Informed maker-educator consent was secured with respect to the confidential treatment of the interview data. Table 1 shows interviewees' details.

3.2 Interviews

We conducted 60–90 min semi-structured interviews with each interviewee. We conducted the interviews remotely using video conferencing and recorded them. Our focus was on understanding the educators' general awareness and understanding of 21st century skills as well as their practice and assessment of these skills in their maker contexts. To achieve this, we interviewed the maker-educators about their teaching philosophies, curriculum and teaching methods in their maker contexts, experiences of teaching in maker contexts, their thoughts about skills development and skills for the 21st century, maker learners' outcomes, challenges they encountered as maker-educators. When examples of 21st -century skills became part of the discussion, we followed up asking for more details on teaching, observing, and assessing these skills.

3.3 Thematic analysis

We first generated transcripts from our interviews using Zoom. Our team reviewed these transcripts along with the Zoom video to correct any transcription errors. Each transcript was, then, divided into discrete responses based on content, producing over 200 quotes from the interview data. We then did an iterative thematic analysis of the interview data.

The goal of the first few rounds of thematic analysis was to find broad emerging themes from the interview data. Once we identified the two main themes of interest -- "practicing 21st century skills" and "assessment practices" -- we aimed to find more granularity and nuanced themes in the later rounds for analysis. Our thematic analysis process involved two research team members discussing emerging macro-

Table 1 Interviewees' details (self-reported)

#	Gender	Profession title	Workplace	Context	Years of experience
P1	Female	FabLab Manager & Educator	FabLab within Private & Secondary school	Maker activities mostly linked to formal school curriculum (some non-formal use of the FabLab)	10+ (as educator), 7+as maker-educator
P2	Female	Maker Facilitator- Educator- Researcher	Private makerspace, maker learners 12–22 years old	Non-formal	10+ (as educator), 7+as maker-educator
P3	Female	Researcher and Teacher Education Instructor	University makerspace	Maker activities linked to formal university curriculum	20+ (as university instructor), 7+as maker-teacher educator & researcher
P4	Male	Maker Educator-Facilitator and Teacher Education Instructor	University makerspace	Maker activities linked to formal university curriculum	10+ (as university instructor), 5+as maker-teacher educator & researcher
P5	Female	Secondary school science teacher and maker educator	Makerspace within Private & Secondary school	Maker activities linked to formal school curriculum	10+ (as educator), 7+as maker-educator
P6	Male	Makerspace educator and teacher trainer	Private makerspace, maker learners 12–22 years old	Non-formal	20 (as educator), 15+as maker-educator
P7	Male	Makerspace practitioner	Private makerspace, maker learners 12–22 years old	Non-formal	20 (as educator), 15+as maker-educator
P8	Female	Makerspace Manager & Educator	Public makerspace, maker learners 12–22 years old	Non-formal	5+as maker-educator
P9	Female	Makerspace Manager & Educator	Public makerspace, maker learners 12–22 years old	Non-formal	5+as maker-educator
P10	Female	Makerspace staff/ educator	Public makerspace, maker learners 12–22 years old	Non-formal	5+as maker-educator
P11	Female	Makerspace Manager & Educator	Public makerspace, maker learners 12–22 years old	Non-formal	5+as maker-educator
P12	Male	Makerspace staff/ educator	Public makerspace, maker learners 12–22 years old	Non-formal	10 (as educator), 5+as maker-educator
P13	Female	Primary school ICT teacher and maker-educator	Public Primary school	Maker activities linked to formal school curriculum	20 (as educator), 7+as maker-educator

categories for codification within the general themes of interest i.e., "practicing 21st century skills" and "assessment practices". Subsequently, two different members of our research team codified the data to identify emerging themes and checked the consistency through the interrater reliability test. It should be noted that we did not

use our own interpretation of the maker-educators' statements, and we did not challenge their definitions or perceived phenomena. Rather, we coded as per how the maker-educators perceived and described the phenomena i.e., the educator labelling a phenomenon as "creative thinking" even if the researchers perceived it as "problem solving". One member of our research team engaged in peer debriefing to improve credibility by interrogating the interpretations and facilitating the refinement of the themes through critical discussion (Spall, 1998). In total, we completed four iterations of coding with inter-rater reliability of over 80% for each iteration. We describe the emergent themes of significance in the next section.

3.4 Findings

Our thematic analysis is presented based on the two macro-categories for codification "practicing 21st century skills" and "assessment practices" which were also the major themes of interest per the research questions of the study.

3.5 Theme 1 - practicing of 21st -century skills in maker contexts

The interviewees made multiple references to 21st -century skills that they practice or deem important to practice during making. Namely, those who work mostly with crafts and arts activities in makerspaces and FabLabs, reported that it is essential for learners to develop skills such as: learning how to learn, communication skills, collaboration skills, design-thinking skills, problem-solving skills, creative thinking skills, and critical thinking skills. Others who work mostly with STEM-related projects, identified some skills in addition to the above; these include flexibility, leadership, life/social skills, resilience and perseverance. They further argued that computational thinking, and technical and coding skills are very important when the outcomes involve electronics and technological prototypes. Figure 1 presents frequency of unique references to the 21st -century skills (one count per unique maker-educator reporting the skill). Regardless of the different nature of the making activities or maker context, five skills seemed to be the most frequently reported. Table 2 summarises how these skills are linked the making practice of the interviewees.

3.5.1 Collaboration skills

Maker-educators considered collaboration and working together as key skills used and developed in maker contexts. A few maker-educators highlighted the differences between the typical classroom environment and the maker context, explaining that "*in contrary to a class*, *a makerspace is designed to be student-centred*, *enabling students to collaborate"* (P1) and *"create together*" (P9), and "*it encourages them to make a plan*, *set goals and collaboratively find a way to reach the goals"* (P2). Along these lines another maker-educator elaborated that "*when students are introduced to the project-problem they are prompted to share their ideas with their groups*, *co-create*, *and present their solutions together*" (P10). Another maker-educator argued that during making activities, students typically work in clusters; thus, the educator aims to promote collaboration and flexibility in the space so that *"students can learn*

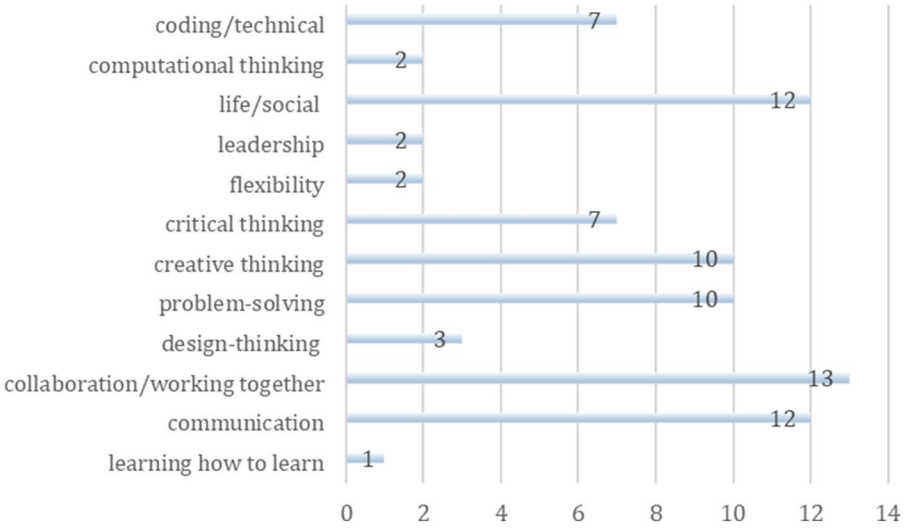

Fig. 1 Frequency of 21st -century skills reported in maker contexts

Table 2 Skills linked the making practice of the interviewees

21st -century skills	Maker activities
Collaboration	• Working together to complete a project • Planning, setting, and reaching common goals • Brainstorming and discussing during ideation • Exchanging knowledge
Communication	• Presenting the results of a making project • Sharing ideas and thoughts during brainstorming and ideation • Interacting with peers and the facilitator • Analysing and discussing the results of experimentation
Creative thinking	• Employing alternative ways to create an artefact or solve a problem. • Sharing different approaches, views, and expressions about the project • Generating new ideas and exploring options • Investigating mistakes
Problem-solving	• Exploring, searching, investigating, and finding evidence to solve a problem • Coming up with ideas, design, prototypes, and making decisions with partial or ambiguous information • Planning a solution by considering the available tools and materials • Design thinking/ Selecting the best idea for a project among several others
Life/Social skills (e.g., Leadership, Perseverance)	• Undertaking responsibility and ownership of something • Helping other people who experience problems during an activity without being instructed to do it • Monitoring and prioritising tasks • Making a plan and setting goals • Being persistent/ Keep working on a project/artefact until it reaches the desired result • Understanding failure • Knowing when to stop one's efforts

from each other [.]and ask their peers for help […], *brainstorm around their ideas and discuss"* (P1). Other maker-educators viewed collaboration in the context of exchanging knowledge, stating that during project work, students *"learn from other students and the staff"* (P2) whilst they *"share their ideas and collaborate to create their final artefact"* (P12). A maker-educator elaborated on the idea of "working together" in the context of health and safety, explaining that "*it is important for the team to learn to work together with safety to reach a goal*, *for example*, *when two people are holding a solder iron together*, *it can be dangerous*, *so these skills are incorporated in every project."* (P6). While this example may not technically refer to collaboration skills, it highlights its importance of sharing and working with others in a highly sensory environment with potentially hazards if tools are not used with safely by all teammates.

3.5.2 Creativity

Maker-educators referred to creativity which is linked to the creation of students' artefacts, the use of their imagination, and the application of alternative methods to create an artefact. They argued that creative thinking is evident when various approaches, views, and expressions are realised through the development of an artefact. They elaborated that the creative thinking process involves students generating new ideas, exploring their options, applying interventions, and finally selecting the best idea. As one interviewee gave an example to explain, *"when the team started the practical work and problems were emerging*, *the facilitators tried to help the students think of alternative ways*, *and to solve the problems that were emerging. Even if the project was the same for all the groups, in the end*, *various alternative approaches were developed"* (P2). Another interviewee explained that creativity and innovation in makerspaces is a long-term process that requires several attempts by the students, i.e., it is essential for them to explore, make mistakes and discuss what went wrong and what could be done differently because *"when something does not work*, *[they] will try to be creative and do it a different way"* (P4). It is noteworthy that these excerpts can be interpreted to overlap with "problem solving" skills or could be seen as "creative problem solving" but we adopted the maker-educators' statements, as they perceived the skill or the phenomenon.

3.5.3 Problem-solving

During the construction of any kind of artefact, students are called to apply problem-solving. Students are called to explore, search, investigate, find evidence, and solve the problem (P13, P5). They are responsible for planning what is essential for their solution in terms of tools and materials and must think ahead of what is needed to solve possible emerging problems (P2). The role of the maker-educator is that of a coach who prompts students to "*explore the solutions themselves and if the first attempts are not working*, *she prompts them to think what might be wrong*" (P3). In some cases, students are given a problem with absolute freedom, and very little guidance, on how to address through making. This freedom entails coming up with ideas, designing prototypes, and making decisions based on partial or ambiguous infor-

mation (P4). A maker-educator discussed how problem-solving intertwines with of design thinking as students learn "*how to think out of the box*, *how to solve problems through design thinking …and these are all skills that are coming out of the projects; we try to start from a problem and continue from there to find a way to possible solutions"* (P1).

3.5.4 Communication

Lots of the maker activities seem to be related to discussing and presenting a project or artefact. As a maker-educator argued, *"makerspaces are spaces for brainstorming and ideation*, *where students are called to communicate their ideas and thoughts and present the current state of their work"* (P2). In some cases, student-makers are even called to *"present their project not only to their teacher but also*, *to people that have never met before"* (P7). An interviewee explained that communication skills are improved *"when students start talking to each other*, *they start analysing*, *use the information they have […] discuss what went wrong with their experimentation*, *what could be done differently"* (P4). Furthermore, the interviewee highlighted the importance of communication skills in peer-to-peer and peer-to-facilitator interaction. A maker-educator reported that her students improved their communication skills as they engaged in maker activities, saying that "*at the beginning [students] were shy but now they feel more confident presenting their work in front of others"* (P2).

3.5.5 Life/social skills

Maker-educators referred to several life/social skills which they considered core skills during making. For example, one interviewee said that life/social skills are *"something that is developed and promoted in the space*, *directly linked to thinking about a creation and the social context in which it is cultivated"* (P10). Another one mentioned that students enhance their self-confidence by working in maker contexts and they become "*more confident in presenting their work at the end*" (P2). Another interviewee elaborated that in makerspaces, students *"take initiative and the more responsibility students are given to take ownership of something*, *the better life and social skills they develop …and in fact*, *90% of learners are doing it*, *rather than following plain step-by-step instructions"* (P6). Similarly, an interviewee provided an example of a student who finished his work and "*took his own initiative to start working with the people aside that were stuck and became a mentor going around helping*" (P8). *"Older students mentoring the younger ones in a makerspace"* was also reported as a life/social skill by other maker-educators (P8, P13). Other maker-educators mentioned "*productivity and perseverance"* skills, as part of life and social skills (P2, P10) whilst, "*monitoring and prioritising tasks is essential life skill for making that allows students to set up a plan and set goals*" (P2). Other maker-educators referred to "*perseverance and persistence"* arguing that students in makerspaces learn to not give up but "*keep on doing something*" until they reach the desired result (P6, P8). Finally, one maker-educator said that she aims to cultivate students the importance of "*understanding failure"* but also "*knowing when to stop*" (P8), qualities that refer to perseverance as a social/life skill.

In general, the interviewees showed awareness of 21st-century skills, yet their practice did not seem to be guided by any formal 21st century skills framework. For example, a maker-educator (P1), whose maker activities were mostly linked to formal school curriculum, reported that she considered how the 21st -century skills are presented in their national school curricula for the STEM domains. Similarly, another maker-educator working in a formal educational setting, commented that he is aware of the 21st -century skills as mentioned in their school curriculum for Science and Technology (P5). A maker-educator working in a non-formal setting, argued that most makerspaces follow national skills frameworks which are applicable at a country level, but mostly draw on their best practice experiences (P6). Although being aware of 21st-century skills, in general, none of the maker-educators reported drawing from any particular framework to guide their maker practice. Rather, they reported drafting their own skills agendas generally informed by (a) references to 21st -century skills in their national school curriculum (P2, P3, P5, P13), (b) recommendations found in the literature (P2, P3, P4, P11, P13) and (c) experience of best practices from their own maker contexts as well as those of others (P1, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12). For example, one maker-educator said: "*I educate myself by considering other makerspaces too. I build a framework of my own based on existing views and practices of mine and of others*" (P1). Another maker-educator reported that *"as a team, we have our own framework based on international research and the culture in which we operate […]; we promote practices about 21st -century skills, even though not explicitly mentioned in our curriculum and activities"* (P4). Through their talk, all maker-educators acknowledged that there is fuzziness around skills development in makerspaces and generally agreed on that "*makerspaces are the most appropriate spaces where this osmosis and development of 21st -century skills can happen*" (P1). Last, there was only one reference to a formal 21st -century framework, namely the Partnership for the 21st -Century Learning (2019), by a maker-educator who applied the framework in her PhD research and consequently, this framework informed her practice as a maker educator (P13).

3.6 Theme 2 - assessment of 21st -century skills in maker practice

Assessment practices for 21st -century skills were mostly absent in makerspaces as evident in the dataset of the13 interviews. Despite maker-educators reporting practicing and observing the development of such skills, emphasis was placed primarily on the development of tangible outcomes. For example, one maker-educator said: "*There is planning for teaching in the makerspace and building of skills. However, assessment does not happen in this space as students focus more on the practical experience of making things"* (P1). Similarly, another maker-educator suggested that *"students are rarely called to reflect or report on the processes they followed to complete a project and maker-educators do not talk about the 21st -century skills when implementing workshops"* (P11). In general, making is seen to take lots of hands-on time leaving no room for assessment. As other maker-educators stressed, due to the demanding nature of making *"neither assessment of 21st -century skills nor scaffolding of these skills"* takes place during making (P1) as *"there is a lot going on, and it is difficult to bring this factor [assessment] into the lesson*" (P2). Based on the views

of another maker-educator, "*most students are not aware of the skills they are developing. They are thinking about the activity itself and they do not do much of reflection on their learning journey*" (P3). Similarly, with reference to younger students, a maker-educator argued that "*it is not easy for students to identify or talk about what skill they are developing at any time. At least*, *primary school students are too young to do this*" (P13).

Although the emphasis is on practice, and formal assessment is unusual in makerspaces, some maker-educators elaborated on informal practices that relate to assessment. For example, one interviewee explained that they "*provide markers that the maker-educators can follow to know if the project is a success or a failure. A project is a success if the project is built*" (P7). Another one said that students are prompted to reflect on their skills after the end of a workshop, stating that *"the student present their artefacts and take the role of a designer who understood how to think of something*, *put it into action*, *think of some ideas*, *select the best idea and present it*" (P11). Other interviewees stated that at the beginning of a making activity, she prompts students to become aware of the future skills needed for their work and ultimately apply these skills for example, "*I want to see your creativity*, *I want to see you collaborating"* (P13). A couple of interviewees argued that 21st -century skills should be communicated to students *"in a clear and explicit way to understand what each skill is*, *especially to the younger ones"* (P9) and could be introduced to students along with the subject matter objectives "*…it could be part of the lesson to teach them these skills. It could be explicit to students that today we are using these skills along with the subject objectives*" (P13). In general, through their statements, it became apparent that most maker-educators endorsed the idea of students becoming aware of their use of 21st -century skills and argued that these skills are evident and should be formally assessed in maker contexts. At the same time, it was well-evident that direct instruction of skills, formal assessment, and any other formal education processes come into tension with the "making ethos" widely recognized in maker-educators' communities. Such arguments came from several maker-educators i.e., *"formal assessment departs from the idea of openness*, *freedom*, *and learner choice in making and could jeopardise the overall ethos"* (P2).

4 Discussion

Despite the opportunities that makerspaces offer for the development of 21st -century skills, understanding how these skills are practiced and assessed in maker contexts has been proven challenging. This study aimed to fulfil this research gap.

In addressing RQ1 *(practicing of 21st -century skills in maker contexts)* maker-educators identify skills that are being practiced or considered important to practice in their maker contexts, most frequently referring to five skills: collaboration, creativity, communication, life/social skills, and problem-solving. This finding is consistent with previous studies, which showed that maker contexts encourage collaboration (Soomro et al., 2022), communication (Gruen, 2018; Soomro et al., 2022), creativity (Timotheou & Ioannou, 2021a, b; Soomro et al., 2022), life/social skills (Marsh et al., 2017; Burke & Crocker, 2020; Milara et al., 2020), and problem-solving (Gruen,

2018; Soomro et al., 2022). The capacity of the maker-educators to report on these distinct skills as in Table 2, provides some evidence of the distinctive nature of the 21st -century skills. Nonetheless, the authors acknowledge some overlap between the descriptions or examples presented by the maker-educators, especially concerning the skills of creative thinking and problem solving. Although it was not the scope of the work to dive deeper in the interviewee's definitions of these skills, these overlaps, replicate previous concerns that these skills are implicit, difficult for students to identify, and problematic in their measurement and assessment (Kipp et al., 2018; Miliou et al., 2023).

Despite their awareness of 21st-century skill and practicing of such skills in maker contexts, maker-educators do not explicitly assess their development. That is, in addressing RQ2 (*assessment of 21st-century skills in maker practice*), most maker-educators did not report using any assessment practices or make efforts to pin-point and raise students' awareness of the skills used during making. Some report practices related to assessment, but only informal ones. The above findings agree with previous research about the lack of assessment practices for 21st -century skills in the context of makerspaces (Miliou et al., 2023, Kipp et al., 2018; Schad & Jones, 2020). According to this study's findings, the reasons for not practicing formal assessment are grounded on (i) the practical nature of making, which emphasizes the development of a tangible result and not skills development as such, (ii) the demanding nature of the making activities, which requires a lot of hands-on time leaving no room for assessment, (iii) the making ethos, which presents maker-educators with choices around what to pursue and how to go about making, and cannot restrict any activities in formal assessment practices. Furthermore, some maker-educators argued that it would be challenging to raise awareness about the use of 21st -century skills in younger students, even if this was to become a goal. Such findings may justify the lack of firm answers about how 21st -century skills are developed and measured in makerspaces (Peppler et al., 2017). Despite the general lack of assessment practices, there were several arguments in favour of students becoming aware of the 21st -century skills they are developing during making.

Based our findings, we can present implementations for future research and practice. First, the study documents some making practices linked to the practicing of 21st -century skills, as reported by experienced maker-educators. Future work could focus on building and introducing 21st -century skills frameworks focused on the maker context. Such frameworks would help to improve learning designs that explicitly enable the development of these skills through making activities, formal and informal. Second, the study documents a lack of assessment practices that enable the collection of evidence concerning the development of 21st century skills during making. Future work could focus on the development of methodologies, instruments, and tools that can help to capture and document the development of 21st -century skills in maker contexts. Educational systems worldwide are responsible for equipping today's students with the necessary competences and skills to apply their knowledge in newfound situations. Practicing and assessing these skills is of paramount importance while makerspaces and FabLabs appear to be ideal spaces to materialize this.

The study comes with some limitations. Our findings reflect the perspectives of 13 maker-educators from four European countries working with young learners in mak-

erspaces and FabLabs and covering a variety of contexts e.g., in-school makerspaces vs. out-of-school makerspaces. The study is in no way exhaustive or comprehensive of 21st century skills practicing and assessment that maker-educators might communicate. We believe that the perspectives of these maker-educators provide a comprehensive understanding of the matter, and that our findings should be transferable and reflect the views of other maker-educators who work in similar contexts. Yet, concerns on subjectivity and reliability that often surround qualitative methods, apply in our work alike. These can be addressed with replication of work and evidence of transfer of the reported findings. We hope that this study will encourage future work looking into how we might design makerspace experiences to support practicing and assessment of 21st century skills.

5 Conclusion

Makerspaces and FabLabs are seen as space designed to foster the development of 21st century skills. This work is an initial step towards understanding the practicing and assessment of 21st -century skills in maker contexts. The study contributes new knowledge in terms of how 21st century skills are being practiced in maker contexts, confirming and extending previous literature in the field. Findings from this study indicate that those skills are currently implicit in the making practice and not formally assessed. The study reveals the lack of assessment practices and the challenging nature of this task. We would argue for the need for instruments, tools, and methods that will enable the tracing of the development of these skills in maker contexts. Assessment of these skills might, then, "talk back" to learning designs for the explicit integration and development of these important skills. Respecting the openness in the making ethos will enable maker-educator to adopt these practices.

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Declarations

Conflict of interest None.

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