Fostering Skills for the 21st century Entrepreur: The Role of Makerspaces

Abstract: Based on a study of a network of fab labs and makerspaces, this article investigates the role that such 'fabrication spaces' can play in fostering 21st century skills. Using a combination of the two main 21st century skills frameworks—DigComp and EntreComp—developed by the EU Commission, we study by the means of two combined qualitative research methods—semi-structured interviews of 13 fab lab/makerspace founders, followed by a focus group with founders and policymaker—the entrepreneurial and digital skills that are fostered by these fab labs and makerspaces. Our results are that while fab labs and makerspaces naturally foster some entrepreneurial 21st century skills, covering the whole range of those skills necessitates to proactively develop specific activities, which might require specific support policies, as fab labs and makerspaces may not have, themselves the required skills. In regard to technical skills, fab labs and makerspaces enable to develop skills beyond what is generally considered as 21st century digital skills, because they combine digital skills with hands-on 'making' skills, since they are themselves mixed environment, both digital and physical. Consequently, the growing importance of 'maker technologies' may force to redefine what 21st century skills should be.
Key words: entrepreneurship; technology education; 21st Century Skills; fab labs; makerspaces

Introduction

It would be hard to argue that digital technologies have not profoundly transformed our economies and societies. Yet, while some parts of our economies have been completely transformed, other parts have seemingly remained unaffected, despite the radical changes taking place around them. Education certainly stands amongst those. In fact, if it was not for the forest of laptop computers flourishing on student desks in lecture halls, it would be easy to think that not much has changed in education as a result of digitisation: aside from some 'administrative' improvements (e.g. digitisation of student records and management) and the availability of some content online (where online slides have replaced printed handouts), teaching delivery modes and organisation, learning assessment, *et cetera* have not, in many places—even in the most 'digitised' countries—significantly changed.

Yet, when it comes to education, digitisation operates as a 'double whammy': on the one hand, it forces education to change, on the other hand, it provides means to change. Since the early 1980s, there has been a growing awareness that the ever-increasing role taken by digital technologies in our societies would eventually lead to completely new skills needed to foster economic prosperity and growth (Dede, 2010). Soon known as '21st century skills', this new set of competencies was rapidly seen as one of the key means to avoid the massive unemployment effect caused by digital technological change (Aubert-Tarby et al., 2018). While 21st century skills do not completely supersede 20th century skills (there is, in fact, a significant overlap between the two), some of the skills required for the 21st century are hard to foster in a traditional classroom environment. A further issue, outlined by numerous studies, such as those from the OECD[1] and the EU[2] Commission, is the need, as a result of ubiquitous digitisation, for these 'new' skills to be spread across widely in the population—far beyond the part of the population who typically has access to higher and further education.

Nonetheless, 21st century skills are not just technology-related skills, far from it. Indeed, digital technologies do not only foster a wide number of business opportunities, they also remove significant barriers to entrepreneurship (OECD, 2017, p. 199). Web 2.0 technologies, for instance, have been highly instrumental in creating the "platform economy", in which many start-ups have striven. Yet, similarly, digitisation may not simply provide more opportunities for entrepreneurship, but, in fact, make being entrepreneurial a necessity. In economies where significant unemployment prevails, entrepreneurship may well be the way out for populations with a very limited access to the job market (Pinelli, 2015).

In this context, the growing popularity of e-learning/distance learning platforms, MOOCs (Massive Open Online Courses) and SPOCs (Small Online Private Courses) is understandable, as they not only enable to foster digital skills, but also increase outreach, not only in terms of population, but also in terms of subject fields. For instance, MOOCs have given means to provide students with a STEM background with business and entrepreneurial skills. Online teaching delivery has also enabled business, economics and social science students to access technological skills, albeit to a lesser extent, as acquiring technological skills often requires hands-on learning activities.

However, in the recent years, digitisation has progressed further and there has been a growing trend, through technologies such as 3D printing (also referred to as 'additive manufacturing'), of digital technologies moving from purely online environments to the 'physical' world. Just as other digital technologies beforehand, these new technologies also require new skills to be developed (Dickens and Minshall, 2016), but also lower further the barriers to entrepreneurship (Rayna and Striukova, 2016). This is in this context that fab labs and makerspaces have emerged. These physical spaces, which provide access to digital manufacturing technologies (e.g. 3D printers, laser cutters, CNC routers), aim to foster the needed new technological skills, at a time

[1] Organization for Economic Cooperation and Development.
[2] European Union.

when access to these technologies still may remain expensive. In addition to these technical competencies, fab labs and makerspaces also foster skills—such as creative thinking, resource management, planning, self-efficacy, teamwork—which are essential entrepreneurial skills. Furthermore, fab labs and makerspaces are drivers of multidisciplinary, as they often combine people from different backgrounds. As such, they enable both engineering/STEM students to acquire business and entrepreneurship skills and business students and entrepreneurs to acquire technological skills.

At a time when fab labs and makerspaces are becoming increasingly widespread and popular—there are nowadays over 1,000 'official' fab labs in the world and many more makerspaces—and we are still looking for adequate means to foster the critically needed 21st century skills, the question arises of whether these 'fabrication spaces' could become a key instrument enabling to foster such skills and, hereby, play a critical role in bolstering future employment and growth capabilities.

This is precisely what this research intends to investigate. Based on a qualitative study (both by means of interviews and focus group) of a large-scale fab lab and makerspace network (the CMIT network), our objective is to assess the role played by fab labs and makerspaces in delivering 21st century skills, both in relation to digital skills and entrepreneurial skills—the main two sets of skills of the 21st century skills.

This article is organised as follows. We first discuss the growing role of fab labs and makerspaces in entrepreneurial education and potentially in acquiring 21st century skills. We then introduce the 21st century framework used in the study, as well as the CMIT fab lab/makerspace network. Once the methodology is presented, we conduct an analysis of the semi-structured interviews and focus group. Finally, a discussion section synthesises the results obtained.

1 Fab Labs, makerspaces and entrepreneurial education

Though the importance of entrepreneurs for the economy was already widely acknowledged in the 1940s, entrepreneurship education in business schools only started to gain popularity in 1970s (Vesper and Gartner, 1997), and it is only in 1983 that the first entrepreneurship course was offered at an engineering school (Katz, 2003).[3]

According to Nabi et al. (2017), who have reviewed 159 articles on entrepreneurship education, most articles claim that it has a positive effect on students' intent to create a new

[3] At University of New Mexico.

venture. Yet, there are different types of entrepreneurship education, which, depending on the views can be either "narrow" (focused on encouraging individuals to start their own business) or "wide" (focusing on making individuals more creative and innovative) (Kamovich and Foss, 2017; Lackues, 2015).

Until recently, however, entrepreneurship education of engineering and science students has had less effect on their entrepreneurial intention than it has had on business students (Maresch et al., 2016). One of the reasons for that is that engineers entrepreneurs often have very little idea of what products society needs and how these products will fit into societies and markets (Phillips, 2018). But, perhaps, as argued in Fayolle (2013), it is also because the tools used to provide entrepreneurship education to engineers are the wrong ones.

One of the recent tools used in teaching entrepreneurship consists in connecting educational programmes to fab labs and makerspaces; because in order to be inventive and creative, it is essential to have an opportunity and a space to do so (Carlson, 2015). These spaces also provide an opportunity for group learning in a psychologically comfortable environment, which is important for acquiring entrepreneurship skills (Harms, 2015).

Fab labs and makerspaces are collaborative spaces fitted with digital—such as 3D printers, CNC machines, laser cutters—and non-digital—woodworking tools, soldering equipment, sewing machines, Lego blocks—equipment. The aim of these spaces is to provide non-specialists with an access to sophisticated technologies, so that they can explore, learn and make (Mortara and Parisot, 2017). Such "fabrication spaces" can be found in a variety of environments, whether public (e.g. schools, universities, museums) or private. Although some are fully open (generally those located in public spaces), others are members only, or even—in the case of corporate makerspaces—fully closed to the outside.

While fab labs and makerspaces are words often used interchangeably, there is effectively a key difference between the two, as fab labs are makerspaces that have signed the Fab Charter of the Fab Foundation (Fonda and Canessa, 2016), an organisation launched by Neil Gershenfeld and Sherry Lassiter to "facilitate and support the growth of the international fab lab network as well as the development of regional capacity-building organisations".[4]

Whether they have signed the Fab Charter or not, these spaces have for objective to help develop both hard (e.g. electronics, 3D modelling, 3D printing, robotics) and soft (creativity, design thinking, prototyping) engineering skills. Furthermore, they also serve as business incubation environment and help develop entrepreneurial skills (Stacey, 2014; Fonda and

[4] http://www.fabfoundation.org/index.php/about-fab-foundation/index.html

Canessa, 2016; Mortara and Parisot, 2017; Browder et al., 2017). The fact that they combine these two different sets of skills is not so surprising, since both entrepreneurship and 'making' require designing and implementing solutions to problems, as well as leveraging and managing resources under uncertainty (Browder et al., 2017).

While the fab lab and makerspace movement is still in infancy, there is already clear evidence that they change how and what people learn in STEM fields, that they help boost creativity and innovation (Beyers, 2010; Blikstein, 2013; Roma et al., 2017), increase self-efficacy (Dubriwny et al., 2016) and promote knowledge sharing (Fleischmann et al., 2016). In fact, though the first fab lab was created in 2001, the philosophy behind the project is rather similar to the 1950s-60s vision of what engineer is. In those days, engineers were seen more as inventors and tinkerers, spending lots of time in a workshop. Since then there has been a graduate shift towards analysis and mathematics (Blikstein, 2013), and as the shift from engineering and design labs to less expensive theoretical classes unfolded (Feisel and Rosa, 2005), the professional engineer became the scientific engineer (Tryggvason and Apelian, 2006). Nowadays, although it is clear that engineering profession still implies a solid knowledge of maths and science, the 21st century demands from engineers new skills in order to adapt to the constantly changing environment (Tryggvason and Apelian, 2006; Galloway, 2007), many of such skills corresponding to those traditionally associated with entrepreneurship.

Yet, it can be noted that the field of entrepreneurial education has not evolved as much in the last 25 years as it would have been expected (Naia et al., 2014). Until recently, programmes aimed at entrepreneurship education either educated for enterprise (i.e. students would be expected to start their own business), through enterprise (in which case the new venture creation process is used for students to acquire particular skills), or in enterprise (in which case students learn from the entrepreneurial environment) (Fayolle, 2008). In contrasts, fab labs and makerspaces could make it possible to combine these three different approaches. Likewise, those spaces can help bring the two extremes of entrepreneurial education—lecture theatre classes, on the one end, and incubators on the other end— together, as they provide an opportunity for entrepreneurship students to practice their entrepreneurial skills in a safe environment and, consequently, make entrepreneurial education more effective.

2 21st Century Skills Framework

Of course, the need for new skills caused by large-scale changes in our economy—in particular through digital technologies—is not solely limited to engineers, but is also relevant for other professions, and for society as a whole (Finegold and Notabartolo, 2010). The discussion related to the development of those new skills necessary for the 21st century started in the 1980s. Since then there have been numerous initiatives setting out to identify what those skills actually were. Though some elements vary slightly according to the source, core 21st century skills typically include analytic skills (problem solving, critical thinking), creativity, communication and collaboration skills, ability to execute, and information processing (Autor et al., 2003; Finegold and Notabartolo, 2010; Boyles, 2012). In addition to these skills, Finegold and Notabartolo (2010) suggested including systems thinking, financial literacy and cross-cultural fluency. In essence, 21st century skills are aimed at equipping people with the ability to explore, create, understand and share (Reeves, 2010).

Though many 21st century skills are similar to the 20th century skills, their amplitude, however, is much greater (Rotherham and Willingham, 2009). For example, the emergence of very sophisticated information and communications technologies since the beginning of the 21st century has led to the growing importance of cooperative interpersonal capabilities (Dede, 2010; Saavedra and Opfer, 2012). Similarly, during the 20th century, problem solving skills were generally taught in an abstract form, without applications, which made them very distant from real world (Dede, 2010), something that is seen as unfit for the 21st century. Furthermore, the growing importance of jobs in services and knowledge work occupations in OECD nations has made obtaining 21st century skills, which are often more critical for these jobs than general skills, become of vital importance (Finegold and Notabartolo, 2010).

Though, overall, policymakers typically agree on what are the main skills and competencies required for the 21st century, there is far less unanimity on how these skills could be best acquired Finegold and Notabartolo (2010). “We don’t yet know how to teach self-direction, collaboration, creativity, and innovation the way we know how to teach long division” (Rotherham and Willingham, 2009). In this context, entrepreneurship classes are often considered as a key source of 21st century skills (Boyles, 2012), and so are opportunities to exploit new technologies (Saavedra and Opfer, 2012; WEF, 2015). As a matter of fact, 21 skills are often taught not as a separate subject, but are rather integrated across the curriculum (Ananiadou and Claro, 2009), or learnt while working on a particular project (Bell, 2010), with particular skills being sometimes singled out and taught separately (Ananiadou and Claro, 2009).

Nowadays, there is a near-unanimous accord on the importance of 21st century skills for future growth and prosperity. While there is generally a broad understanding of what those skills should be, it is only relatively recently that attempts were made to carry out a comprehensive investigation of what those skills precisely are.

Starting in 2005, through the JRC Learning and Skills projects, the EU Science Hub of the European Commission set out as one of its objectives to build a comprehensive listing of 21st century skills.[5] While the programme has now produced several frameworks related to different types of stakeholders and contexts, two particular ones are directly relevant to the question at hand: DigComp and EntreComp. DigComp (Ferrari, 2013), or “Digital Competence Framework”, provides a list of skills related to digital and information technologies required for citizens of the 21st century, in particular in relation to future jobs. In contrast, EntreComp (Bacigalupo et al., 2016), or Entrepreneurship Competences, aims to provide a reference framework of what entrepreneurship as a competence is. As noted by the European Commission, both EntreComp and DigComp “aim to comply with the Commission’s top priority on “Jobs, Growth and Investment” and to the Europe 2020 flagship initiative Agenda for New Skills for New Jobs.”[6]

Table 1 presents the 21st century framework used in this research, which results from the combination of EntreComp skills (EC1 to EC 3) and DigComp skills (DG1 to DG5).

Table 1: List of 21st century Skills (and codes)

	Entrepreneurship Skills (EntreComp)
EC1	*Ideas and opportunities*
EC1.1	Spotting opportunities
EC1.2	Creativity
EC1.3	Vision
EC1.4	Valuing ideas
EC1.5	Ethical and Sustainable Thinking
EC2	*Resources*
EC2.1	Self-awareness and self-efficacy
EC2.2	Motivation and perseverance
EC2.3	Mobilising resources
EC2.4	Financial and economic literacy
EC2.5	Mobilising others
EC3	*Into Action*
EC3.1	Taking the initiative
EC3.2	Planning and management
EC3.3	Coping with uncertainty, ambiguity and risk
EC3.4	Working with others
EC3.5	Learning through experience
	Digital Skills (DigComp)
DC1	*Information and data literacy*
DC1.1	Browsing, searching and filtering data, information and digital content
DC1.2	Evaluating data, information and digital content
DC1.3	Managing data, information and digital content
DC2	*Communication and collaboration*
DC2.1	Interacting through digital technologies
DC2.2	Sharing through digital technologies
DC2.3	Engaging in citizenship through digital technologies

[5] https://ec.europa.eu/jrc/en/research-topic/learning-and-skills

[6] https://ec.europa.eu/jrc/en/entrecomp

DC2.4	Collaborating through digital technologies
DC2.5	Netiquette
DC2.6	Managing digital identity
DC3	*Digital content creation*
DC3.1	Developing digital content
DC3.2	Integrating and re-elaborating digital content
DC3.3	Copyright and licences
DC3.4	Programming
DC4	*Safety*
DC4.1	Protecting devices
DC4.2	Protecting personal data and privacy
DC4.3	Protecting health and well-being
DC4.4	Protecting the environment
DC5	*Problem solving*
DC5.1	Solving technical problems
DC5.2	Identifying needs and technological responses
DC5.3	Creatively using digital technologies
DC5.4	Identifying digital competences gap

3 The CMIT Fab Lab Network

One of the main issues when investigating fab labs and makerspaces is their heterogeneity. Besides the sole issue of whether they have signed the Fab Charter or not (and, hence, are ‘actual’ fab labs), arises the problem of the extremely wide diversity of circumstances (e.g. some are private, others are public; some are open, others are closed) and even amongst ‘official’ fab labs, tremendous differences prevail (e.g. some are subsidised, others are independent; some are located within schools or universities, others in residential areas). Consequently, this renders any generalisation particularly risky.

This is why the CMIT (Centre for Maker Innovation & Technology) network makes such an interesting object of study. Launched in 2013 by the Russian Science and Technology Development Fund for SMEs (STDFS) to tackle an observed sharp decline in STEM and engineering skills in the population, the CMIT funding programme aims to support the development of fab labs and makerspaces countrywide. Yet, unlike other fab lab/makerspace funding programmes, the CMIT programme is surprisingly homogeneous and non-prescriptive: it offers a one-shot 7 million RUB (roughly €110,000) to entrepreneurs to purchase equipment for their space (e.g. computers, 3D printers, CNC[7] routers, laser cutters) in exchange for one unique requirement: that 40% of the activities of the lab will be offered free-of-charge and will aim to foster skill development such as

> usage of digital manufacturing; development of new competencies related to entrepreneurship and engineering; sustenance to those studying engineering in

[7] Computer Numerical Control.

testing, implementing and commercialising their innovative ideas by providing them with digital manufacturing equipment.[8]

However, besides these general guidelines, no particular requirements (aside from the 40% rule) are given, and space founders are free to organise their educational activities as they see fit. While all CMITs necessarily have a focus on education to a certain extent, this does not mean that it is their sole and only focus. As a matter of fact, some CMITs have their activities entirely dedicated to education, while others do not have significant educational activities beyond the 40% required. Likewise, applicants are free to choose the location of their CMIT and must (as no other funding is provided) find their own way to make their fab lab sustainable. Hence, all the CMIT spaces begin in very homogeneous situations (they are funded by entrepreneurs who receive a set funding to purchase equipment), but evolve potentially very differently, since they are free to choose which activities they carry out, as well as which business model to apply. Consequently, in regard to the development of engineering and entrepreneurial skills, the CMIT network is (relatively) devoid of the usual biases and idiosyncrasies of other fab labs and makerspace networks, as they emerge in a rather bottom-up environment (aside from the original top-down impulse related to the funding programme).

Since 2012, 240 CMITs were funded by the programme, out of which, 170 are currently operating. CMITs are mainly located in Russia (some of them are in neighbouring countries), in all Russian regions and in cities of very different sizes.

4 Methodology

Fab labs and makerspaces are a relatively recent phenomenon. While the first fab lab opened in 2003 (Gershenfeld, 2012), it is only over the past five years that the number of such spaces has significantly grown. Consequently, a fab lab and makerspace "dominant design" has not emerged yet, and these spaces are still very much evolving. Because of that, this research is based on an exploratory methodology, as this methodology is especially relevant when issues that are being studied are still evolving (Yin, 2003).

For this research work, we combined two exploratory methodologies: semi-structured interviews of CMIT founders located across Russia and a focus group. The interviews enabled to uncover the different skills practically fostered by the CMITs, while the focus group provided indications as to which skills were deemed particularly important by the CMITs, as well as which types of activity were thought to foster such skills.

[8] http://innoagency.ru/ru/application/support/cmit-support

This dual qualitative methodology was used to obtain richer data than with just interviews. Indeed, focus groups provide with an ability to observe interaction on a topic and also to see how opinions are formed, expressed and sometimes modified (Morgan, 1996; Barbour and Kitzinger, 1998). In comparison to traditional interviews, they provide a greater variety of interactions with participants, as well as more open and sharp discussion (Morgan, 1996; Spiess et al., 2015). Focus groups are often used after individual interviews, as they allow to focus on particular issues, as well as to confirm previous research findings (Ritchie et al., 2013).

The choice of sample is particularly critical for explorative studies (Miles and Huberman, 1994). In particular, sample size—which reflects the representativeness of the study—and sample composition—which reflects the diversity of the sample and therefore its exhaustiveness—are important. The sample size should provide scope for possible generalities, but remain small enough for individuals to keep their own identity (Robinson and Smith, 2010). According to Guest et al. (2006) saturation (a point where no more new information is collected) is reached very quickly, and already six interviews can enable to collect most of the critical information, with perfect saturation often reached with twelve interviews. Following Silverman (2013), we decided to monitor data collection as it progressed and alter sample size according to the results of the interviews. No new themes were added during the ninth interview, four more interviews were nonetheless conducted to ensure that saturation had effectively been reached.

In an exploratory study, diversity is critical to ensure the full extent of the phenomenon is observed. Consequently, the 13 CMITs in the study (Table 2) were chosen according to their region (the study covers 6 out of 8 administrative regions of the Russian Federation), their specialisation (some of the 13 CMITs are mostly education focused, while others have specialised in enterprise activities; some of the CMITs in the sample have a dedicated entrepreneurship programme, while others have not), their location (the population of cities where the 13 CMITs are located ranges from 7,000 to 12 million people),[9] as well as whether they had signed the Fab Lab charter (5 of them) or not (in which case, they are, actually, makerspaces). Because semi-structured interviews are the most common type of interviews used in qualitative research (Alvesson and Deetz, 2000) and are one of the most effective means of gathering information (Kvale and Brinkmann, 2009), this form of interviews was used for the 13 CMIT founders. Interviews lasted between 30 and 45 minutes. During the interviews, participants were asked to keep to the topics defined in the interview guide, but yet encouraged to speak freely (Yin, 2003).

[9] Population is not listed in the table to protect anonymity.

The topics discussed during the interviews were based on informal discussions authors had during their visits to CMIT centres in 2013–2016 as well as during a CMIT meeting held in Moscow in summer 2016, where many CMIT founders were present. Topics were

1. Detailed information about the CMIT.
2. Background of the CMIT founder.
3. Objectives and motivation for opening a CMIT.
4. Development of the CMIT (e.g. choice of location, staff hire) before and after funding was obtained.
5. Activities carried out at the CMIT and reasons for such a choice.
6. Business model of the CMIT and sources of revenues.
7. CMIT users and their purpose.
8. Involvement of the local community in delivering activities (whether paid or not) at CMIT.
9. Projects and activities carried out at CMIT that had social impact at local, regional, and national levels.

Interviews were recorded, transcribed, and then coded independently by two investigators, to enhance confidence in the research findings (Denzin, 1970; Yin, 2003).

Table 2: List of Centres for Maker Innovation and Technology (CMIT) whose founders were interviewed (* are official fab labs, † have an explicit entrepreneurship programme).

Code	Region	Founded	Funded	Location	Focus
NC1*†	N. Caucasus	2009	2014	University	Agricultural machinery, R&D
NW1*†	North West	2011	2013	University	Education
C2*†	Central	2013	2013	Residential	NPD, start-ups
V1†	Volga	2013	2013	Techno-park	Biotech, medical, start-ups, R&D
C4*	Central	2013	2013	University	Design
S2†	Siberia	2013	2013	Incubator	Education
S1†	Siberia	2013	2013	University	Robotics, electronics
C1	Central	2014	2015	Art cluster	Education, design thinking, prototyping
C3†	Central	2014	2015	Residential	Classes for schoolchildren
NW2*	North West	2014	2015	College	Classes for schoolchildren
NC2	N. Caucasus	2016	2016	Youth centre	Education
C5	Central	2016	2016	Residential	Classes for schoolchildren
C6	Central	2016	2016	University	Education, biotech

Table 3: List of Centres for Maker Innovation and Technology (CMIT) who took part in the focus group (* are official fab labs, have an explicit entrepreneurship programme).

Code	Founded	Funded	Location	Focus	Interv. Code
P1	2016	2016	University	Education	C6
P2†	2014	2015	Residential	Classes for schoolchildren	C3
P3†	2013	2013	Techno-park	Education, industrial design	—
P4†	2016	2016	Residential	Education, NPD	—
P5†	2013	2015	Techno-park	Education, NPD, prototyping	—
P6	2015	2015	Residential	Classes for schoolchildren	C5
P7	2013	2017	Techno-park	Education, drones	—
P8*†	2013	2013	Residential	NPD, start-ups	C2
P9	2014	2015	Art cluster	Education, design thinking, prototyping	C1

In order to complement the findings obtained from the interviews, the focus group took place shortly after the 13 interview was conducted. We used a scheduled regional CMIT meeting to recruit focus group participants, thereby using piggyback approach (Krueger and Casey, 2000).[10] The region in question was of particular interest, as over 60 CMITs are located there. Nine of the meeting participants took part in the focus group (Table 3). Five participants came from CMITs that had been previously interviewed (in which case the interview code is mentioned in the table).[11] The 10 participant in the focus group was a representative of the Moscow Region Department of Innovation, in charge of overseeing the CMIT programme, as we wanted to have a programme representative taking part in the discussion. The number of focus group participants is consistent is what is usually advised in the literature (Krueger and Casey, 2000).

5 Semi-Structured Interviews

As mentioned in the previous section, the 13 interviewees were asked about their objective and motivations for opening a CMIT, the activities carried out at the CMIT, as well as the reasons behind this choice of activities, and who the CMIT users were and what their purpose was when coming to the CMIT. The answers to these questions (as well as, when appropriate, their answers to other questions) were used to identify the particular 21st century skills fostered by each CMIT.

The 21st century skills frameworks used to analyse the interview transcripts are the DigComp and EntreComp frameworks presented in Section 1 and summarised in Table 1. While commissioned by the EU Commission, those frameworks—to this day the most comprehensive 21st century skill frameworks—built based on academic research, are not country specific, but instead relate to skills that people in the 21st century should have, regardless of the country they live in (or come from). In the case of Russia, where most CMITs are located and where the

[10] The participants of a piggyback focus group gather for a different event and focus group is conducted during their free time.

[11] Aside from one CMIT (P6/C5), for which two different people were involved—the founder/director in the interview, and the deputy director in the focus group—people interviewed and taking part in the focus group were the same.

CMIT programme originated from, no comprehensive 21st century skill framework has been produced yet. However, considering the key objectives of "Jobs, Growth and Investment" shared by Russia alongside the EU and OECD,[12], Russia's progressive integration in EU educational frameworks [13] and its official application to formally join OECD as a member state—the roadmap to accession embedding key elements is related to education policy [14]—make DigComp and EntreComp highly relevant when investigating 21st century skills in this country as well.

It is important to note that, at this interview stage, CMIT founders were not asked directly about the skills their CMITs enable to foster. The reason for that was to avoid turning the interview into a skill listing (which most likely would have been non-exhaustive), but instead to reveal indirectly, through the activities carried out—or, at times, directly, when spontaneously mentioned by the interviewees—the skills promoted by the CMIT. In contrast, participants in the focus group were directly asked about the skills their CMIT aims to foster (as well as the activities enabling to foster them); this dual approach, enabling to have both an 'unbiased' view and a personal perspective of these questions, provided a clearer picture.

5.1 Entrepreneurial vs. Non-Entrepreneurial CMITs

The first important aspect that emerged from the interviews is that some of the CMITs (NC1, NW1, C2, V1, S2, S1, C3) have an explicit focus on entrepreneurship education, while others (C3, C1, NW2, NC2, C5, C6) do not. For instance, V1 stated:

> From the very start, we wanted to link [our activities] to commercialisation of products […] We even argued with [the CMIT] programme organisers that young people can create projects which can be commercialised […] and this is exactly what we are trying to do now.

The difference between focusing solely on fostering technology skills and fostering both entrepreneurial and technology skills is further pointed out by V1:

> We don't want to raise "innovation meat" that will be used by other companies, but rather create leaders who will be creating teams around themselves […] We raise techno-entrepreneurs.

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[12] https://tass.ru/forumsochi2018/articles/5102936
[13] e.g. the Bologna process back in 2003, which has led to radically change of the Russian higher education system from a one-tier degree system to a two-tier degree system and then the ERASMUS+ programme
[14] http://www.oecd.org/russia/therussianfederationandtheoecd.htm

In terms of activities used to foster entrepreneurial skills, all 'entrepreneurial' CMITs use projects. Whereas all CMITs (and possibly all fab labs and makerspaces) carry out projects, the 'entrepreneurial' CMITs go beyond the sole realisation of a product and require some form of commercialisation to take place, thereby putting project participants in an entrepreneurial mindset:

> The kids […] need real practical projects. If they do a project, it has to be a project we can commercialise. We explain them how to sell it, it has to be a finalised product. [V1]

> For each project that is developed [in our CMIT], we try to find an external mentor. [C2]

In addition to projects, some of the 'entrepreneurial' CMITs [NC1, NW1, C2, C3] run courses and (master) classes related to entrepreneurship. For instance, NC1 runs monthly classes devoted to helping participants acquire entrepreneurial skills. Likewise, C2 regularly organises master classes with external speakers who come to talk to CMIT members about finance, marketing, and other topics would-be entrepreneurs need to know about.

Besides classes, three of the 'entrepreneurial' CMITs even run full educational programmes embedding elements of entrepreneurship education. C3 runs a "Kids MBA", during which they teach children about business and entrepreneurship. Catering for an older public, NW1 (located on university premises) is involved in an MSc in Digital Manufacturing programme, where business and entrepreneurial skills are a part of the learning outcomes. Finally, C2 runs a 2-month "Engineering Academy" aimed at 15+ year-old children who, as a part of the curriculum, work with engineers from the industry, in what is, for C2, akin to a "business accelerator for [young] engineers".

Fostering entrepreneurial skills within CMITs does not solely rely on the activities and projects that are carried out at the CMIT. Instead, in order to do so, some of the CMITs have created dedicated structures or established links with existing entities. S1, for instance, has created a business incubator within his CMIT, while NW1 has set up partnerships between her CMIT and other incubators (including the incubator of the university her CMIT is located in).

Besides incubators, which directly aim to foster and develop entrepreneurial skills, co-working spaces are also known to be instrumental in developing such skills (Fuzi, 2015; Bouncken and Reuschl, 2018). For this reason, NW1 has opened in her CMIT a co-working space that hosts between 200 and 300 people, both individuals and teams. Likewise, NC1 sees co-working spaces as the "missing link" between "school kids, university students, and entrepreneurs” and, as a result is planning to open in the coming months a “co-working centre for engineers” that will mix these three populations “so that [they] could help each other and learn from one another”. This idea of bringing together different populations as a way to develop entrepreneurial skills is also shared by C3 and C2:

> Our CMIT focuses on kids. There are CMITs focusing on students. The idea is to create something which will combine them, as well as entrepreneurs. [C3]

> [It is] not only school kids with students, students with start-ups, but also start-ups with schoolkids, [this] happens all the time [C2]

In this respect, it is interesting to note that interviewees consider that entrepreneurship education has to start early. Besides NC1, C3 and C2, V1 considers that some entrepreneurial skills, such as leadership, should be taught to children as young as “preschoolers aged 3”.

It is interesting to note that similarly to Dodd and Hynes (2012); Mosakowski et al. (2013) respondents have mentioned that the environment can be both a driver and a hindrance for the development of an ‘entrepreneurial’ CMIT. For instance, V1 mentions a clear push for entrepreneurial activities from the regional government:

> One of the Governor’s goals is to make the region such so that young people want to stay, and he considers that one of the factors that can play this role is that we create start-ups. A school kid at the end of the school creates a start-up, which he/she also runs as a student and at the end it becomes something profitable.

However, other times the environment plays against ‘entrepreneurial’ CMITs:

> This is quite painful for us, as we are trying hard, but not with a lot of success. So far, we don’t have a single project which would have grown into a start-up and would have started to bring some money […] even though we have a business incubator […] [Region name] is not really about entrepreneurship. We have oil and gas, so people do not need to do entrepreneurship. [S1]

This kind of environment can be a reason for the ‘non-entrepreneurial’ orientation of a CMIT:

> There are not a lot of entrepreneurial activities in the area. Some people come to the centre to create a prototype of their innovative idea (e.g. to improve efficiency) but not really to create a start-up. [NC2]

But this is not the only reason. Illustrating well the current debate between “technology start-ups”, who simply use existing technology, and “deep-technology” start-ups, who introduce new radical and research-based technologies (de la Tour et al., 2017), NW2 mentions the trade-off between fostering entrepreneurial skills alongside technology skills, and developing more advanced technology skills:

> Technology entrepreneurship is difficult to execute if the 'technology' element is weak. Quite a few technology start-ups are simply copying existing ideas. We need those who have [advanced] programming skills, technology skills, etc.

Another trade-off related to teaching entrepreneurship skills is mentioned by C6, whose CMIT is located at university premises and specialises in biotechnology. She stated that her CMIT members generally feel strongly about promoting science, which tends to reduce the appeal of creating a start-up. Yet, in this respect, it can be noted that not all 'entrepreneurial' CMITs see creating a start-up and being profitable as the (only) ultimate goal. S1, C3 and S2 put a strong emphasis on social entrepreneurship. However, in those cases, the balance between fostering start-ups and having social impact is not always obvious:

> I am still not sure where the priorities should be: on the one hand it is important to make sure there will be a demand [for the product] and that it will be eventually bought, but on the other hand, if it is only about profit (and for example not about fulfilling a social need), it is perhaps not so great either. We believe that social side is very important. How to balance the two is not very clear for me at the moment. […] The kids have created a bracelet that enables to alert of upcoming epileptic fists, but we don't think that we should commercialise projects which help physically impaired people.

Yet, 'non-entrepreneurial' CMITs have not necessarily chosen to be so because of the above-mentioned trade-offs. Sometimes it is because they, themselves, lack the necessary skills. C5, for instance, mentions that several start-ups who used the CMIT for their prototypes had asked them questions related to business and legal matters, but that they were simply unable to help them. However, this issue is not only happening with non-entrepreneurial' CMITs, as S1 stated that one of their problems was that they "do not have people who know how to take a product to market".

Finally, being a 'non-entrepreneurial' CMIT (i.e. not running activities devoted to fostering entrepreneurial skills) does not mean that you do not help develop entrepreneurial skills, as they do help start-ups and would-be entrepreneurs to improve their skills:

> Actually, [the start-up who come to our CMIT] have some ideas on paper, but most of them are not manufacturable. So we're trying to explain them how to do this better, so it can work, making some prototypes, so yeah [we help start-ups]. [C1]

5.2 Entrepreneurial Skills

Interviews transcripts were analysed to assess which entrepreneurial skills were fostered in each of the 13 CMITs whose founders were interviewed. This identification of skills occurred either directly—when the interviewee mentioned the skills directly (e.g. "once they have the scientific base, they can start being creative" [C6], corresponds to skill EC1.2–Creativity)—or indirectly, based on an identification of the skills typically provided by a particular activity taking place at the CMIT and mentioned in the interview (e.g. prototyping typically fosters "learning through experience"—skill EC3.5—and "structured ways of testing ideas and prototypes from the early stages", which is part of skill EC3.3).

5.2.1 Ideas and Opportunities (EC1)

Looking at the first group of entrepreneurial skills *EC1–Ideas and Opportunities*, interviews reveal some disparity, not only between the skills in this group, but also between the CMITs. Within this group, only one skill is covered by all 13 CMITs: *EC1.2–Creativity*. This is not so surprising as fostering creativity is one of the '*raisons d'être*' of fab labs and makerspaces.

The three next skills—*EC1.1–Spotting Opportunities*, *EC1.3–Vision*, and *EC1.4–Valuing Ideas*—generally come hand in hand, as they are related to commercialisation.[15] Unsurprisingly, these skills are more particularly fostered at *entrepreneurial* CMITs (all 7 of them), by means of projects, with only one *non-entrepreneurial* CMIT (C1) reporting engaging in this kind of skill development.

Hence, our interviews show that while *non-entrepreneurial* CMITs appear to foster *any kind* of creativity, CMITs aiming to foster entrepreneurial skills target specific forms of creativity that is related to actual market opportunities. For instance, as mentioned above, V1 wants "real practical projects […] [they] can commercialise". Likewise, C3 looks for projects for which there is "a demand" and "will eventually be bought". Other interviewees at entrepreneurial CMITs provided examples of projects carried out at their CMIT that led to commercialisation and, besides creativity, required the ability to spot opportunities. C2 mentioned a storytelling

[15] Indeed, developing a new product for commercialisation, besides creativity, requires at the very least the ability to spot an opportunity [EC1.1], to "recognise the potential an idea has for creating value and identify suitable ways of making the most out of it" [part of EC1.4], and to "develop a vision to turn ideas into action" [part of EC1.3].

teddy bear, the idea of which emerged after one member observed busy parents. NC1 provided the example of children who created their own version of the Monopoly—with local streets and shops—which went for sale in local stores.

However, these three skills are not only related to commercialisation. Indeed, four of the seven *entrepreneurial* CMITs (S1, C3, S2, NW1) also put an emphasis on *social* entrepreneurship. In such a context, developing the ability to spot opportunities, value ideas, and to turn them into action does not necessarily lead to commercialisation, but instead to free diffusion. As noted above, children at C3 created a wristband that alerts of upcoming epileptic fits. Members at S1 developed a "hand extension" (a long stick with tentacles) that enables people in a wheelchair to pick up objects from the floor. At S2, a 12-year-old created a robot with a camera that was "going to school" instead of his physically impaired friend who had to stay home. Children at NW1 developed a new bionic hand for a friend who was born without a hand, improving the original design to make the hand look more attractive, so that their friend was not ashamed of wearing it any more.

As noted above, only one *non-entrepreneurial* CMIT founder explicitly mentioned activities fostering *EC1.1–Spotting opportunities*. C1 runs projects based on a particular theme, pushing children to identify opportunities related to that theme. For instance, one of the themes was "ageing population". A group of children spotted the opportunity to develop a "light doorbell", since elderly people tend to see (at least light) better than they hear.

All these examples show that the activities provided at these CMITs foster more than just the ability to be creative, but also the capacity to identify opportunities [EC1.1], to assess its value [EC1.4], and to develop a vision of how to turn the original idea into action [EC1.3].

Interviews revealed that last skill of this first subgroup—*EC1.5–Ethical and Sustainable Thinking*—is carried out by five out of 13 of the CMITs, i.e. by four of the seven *entrepreneurial* ones (S1, C3, S2, NW1) and one of the *non-entrepreneurial* CMITs (C1). As noted above, these four *entrepreneurial* CMITs put an emphasis on social entrepreneurship, while C1 chooses topics for the projects (e.g. ageing population) carried out at the CMIT that are chosen to foster this kind of skill. In this respect, it is to be noted that interviews revealed that this particular type of skill is only fostered through projects (i.e. there are no courses or master classes devoted to ethical and sustainable thinking).

5.2.2 Resources (EC2)

In regard to *E.2–Resources*, there is one set of skills—*EC2.3–Mobilising Resources*—which is fostered by all 13 CMITs. This is because all the CMITs—either through classes or projects—

teach their members to “get and manage the material, non-material and digital resources needed to turn ideas into action” and “make the most of limited resources”, which are two of the three components of *EC2.3–Mobilising Resources*.[16]

The second most prevalent skill within this group is *EC2.5–Mobilising Others*, which includes “inspire and enthuse relevant stakeholders”, “get the support needed to achieve valuable outcomes”, and “demonstrate effective communication, persuasion, negotiation and leadership”. Eleven of the 13 CMITs interviewed—all seven *entrepreneurial* CMITs and four *non-entrepreneurial* ones—carry out activities that enable to foster (at least partially) this set of skills. The reason for that is that all 13 CMITs either run group projects or classes that entail group work. Within this context, “relevant stakeholders” are both fellow members whose help is needed to carry out the task, and teachers/animators whose assistance may be required. Moreover, typically, group work, whether in a long-term project or a class, includes pitches and presentations, for instance, to select the project amongst several options the group is going to work on.

Yet, while both *entrepreneurial* and *non-entrepreneurial* CMITs address this set of skills, the skills which are actually fostered are likely to be different. Indeed, in *entrepreneurial* CMITs, relevant stakeholders—typically, potential customers, mentors, funding bodies and investors, resellers—are located outside of the CMIT. This means that the third component of EC2.5 (“demonstrate effective communication, persuasion, negotiation and leadership”) is far more likely to be developed in *entrepreneurial* CMITs. For instance, C2 mentioned that they help their members “gain publicity […] and showcase their projects at different events” and that one of the projects was even “shown to [Russia’s] Prime Minister”. C2’s team also help their members “obtain money”, either through grants, investors, or even crowdfunding campaigns, all of which are instrumental in fostering EC2.5 (its third component, in particular). Likewise, D1’s CMIT puts a strong emphasis on “creating leaders that will form teams around them”—again a clear indication that EC2.5 is fostered in this CMIT.

‘Advanced’ EC2.5 might nonetheless still be fostered in *non-entrepreneurial* CMITs. C4, for instance, organises as a part of his CMIT’s activities “design nights” during which CMIT members provide decorations, illuminations, as well as music, to the local public spaces, such as parks. Organising such events, where the stakeholders are the police, the city hall, health and safety services, etc. require (and develop) all three components of EC2.5 skill set.

[16] The third component of EC2.3—“get and manage the competences needed at any stage, including technical, legal, tax and digital competences”, however, is unlikely to be fully addressed by all the CMITs.

EC2.2–Motivation and Perseverance was identified in nine of the 13 interviews. All seven *entrepreneurial* CMITs provide activities enabling to foster such skills, as well as two of the *non-entrepreneurial* CMITs (C6 and NW2). In regard to *entrepreneurial* CMITs, it is mainly their focus on commercialisation that helps fostering such skills. Indeed, getting from an original idea to a finalised product that can be commercialised is a lengthily process, generally prone to temporal failures and setbacks, and seeing this through does require both motivation and perseverance. Yet, *non-entrepreneurial* CMITs still have means to foster such skills, through long-term projects (C6) or by encouraging children to take part in robotics competitions (NW2).

Most of the interviewed CMITs —i.e. five out of seven *entrepreneurial CMITs* (C2, V1, NC1, C3, NW1) and two out of six *non-entrepreneurial* CMITs (C6, NW2)—also carry out activities enabling to foster *EC2.1–Self-Awareness and Self-Efficacy*. This mainly happens through the promotion of independent work:

> CMIT employees do not babysit participants, even when they are schoolchildren [C2]

> [Children] learn by making things and doing things on their own [C6]

and by helping children believe in themselves:

> We give kids confidence that they can create anything [V1]

> We tell other kids about successful examples, to make them believe in themselves [NW1]

even though this might take time:

> Kids need a transition period, so that they start believing in themselves [C2]

Unlike for other skills, interviews did not reveal any specific difference between *entrepreneurial* and *non-entrepreneurial* CMITs in regard to *EC2.1–Self-Awareness and Self-Efficacy* (beside the seemingly lower proportion of the latter who engage in fostering these skills).

EC2.4–Financial and Economic Literacy is the final set of skill in this group. Unsurprisingly, interviews revealed that only (and all) *entrepreneurial* CMITs carry out activities to foster this kind of skill. However, this does not necessarily mean that the CMIT, even an *entrepreneurial* one, is able to provide the skills necessary for a successful commercialisation. For instance, S1, as noted above, despite having an incubator and attempting to foster this type of skill, has not yet been able to help just even one start-up commercialise its product.

5.2.3 Into Action (EC3)

As noted in Carlson (2015), the ability provided by fab labs and makerspaces to 'get into action' is very much what makes them so important in entrepreneurship education, because they provide a 'hands-on' experience. And, indeed, the interviews confirmed that all 13 CMITs provide activities that enable "learning through experience" (EC3.5) and "working with others" (EC3.4). All CMITs offer their members opportunities to work on long-term projects at their own initiative (EC3.1), which fosters "planning and management skills" (EC3.2). Finally, since all CMITs offer prototyping facilities, they "include structured ways of testing ideas and prototypes from the early stages, to reduce risks of failing", which is one component of *EC3.3–Coping with Uncertainty, Ambiguity and Risk*. A second component of EC3.3—"*make decisions when the result of that decision is uncertain, when the information available is partial or ambiguous, or when there is a risk of unintended outcomes*", is also generally addressed. Indeed, projects carried out at the CMITs—e.g. epilepsy warning wristband, 'school robot', bionic hand—are generally both complex, since they require a combination of 3D printed parts, with mechanical parts and electronics, and exploratory (the examples provided sat at the 'fuzzy front end' of innovation). In contrast, the last component "handle fast-moving situations promptly and flexibly"—is probably only fostered in special circumstances, such as the various competitions the CMITs may encourage their members to take part in.

5.3 Digital Skills

In regard to the Digital skills fostered at the CMITs, the situation is much more homogeneous than for entrepreneurial skills, though some level of disparity still prevails in some cases. Regardless of whether they are entrepreneurially minded or not, CMITs provide access to a range of digital (e.g. 3D printers, laser cutters, CNC routers, computers, 3D scanners) and non-digital (e.g. soldering stations, woodwork tools, sewing machines) equipment. In the case of CMITs, because of the nature of the funding—a set 7 million RUB funding—and the relatively low choice available for some types of equipment (e.g. 3D printers, 3D scanners, laser cutters), the equipment available at the different CMITs is particularly homogeneous.

5.3.1 Information and Data Literacy (DC1)

Because of the nature of the equipment used as a part of the CMITs activities, all CMITs foster *DC1–Information and Data Literacy*. For instance, printing an object with a 3D printer leads to "browsing, searching and filtering data, information and digital content" [DC1.1] (for instance, finding a 3D model to print on online repositories such as Thingiverse[17] requires browsing, searching and filtering data, information and digital content), "evaluating data, information and digital content" [DC1.2] (e.g. by assessing whether a 3D model can be printed successfully with a particular equipment or a particular material), and "managing data, information, and digital content" [DC1.3]. The development of these skills is further enhanced by the fact that, as noted above, CMITs promote independent work. In this respect, CMITs do not only promote digital skills related to 'digital manufacturing' equipment, but digital skills in general, as children are encouraged to "look online" [C2] or to follow "free online courses" [C3]:

> We will teach [them] and guide [them], but they also need to look for info on their own. If they have a question, we can direct them towards an article or information on the Internet. They read it and then we will discuss to see whether they understood it. [S1]

5.3.2 Communication and Collaboration (DC2)

In contrast, the effect of CMITs on *DC2–Communication and Collaboration* skills appears weaker. While all CMITs are conducive of *DC2.4–Collaborating through Digital Technologies*—all offer group work revolving around digital technologies—only two of the interviewees mentioned activities enabling to "interact through digital technologies" [DC2.1], i.e. the 'school robot' project carried out at S2 and the "Design Nights" organised by C4. Indeed, while CMIT activities do foster interactions between members, these are typically done face-to-face and do not significantly involve digital technologies, as people are in the same room. Likewise, and for the same reason, only C1 mentioned something related to "sharing through digital technologies" (children making videos of their invention and sharing them online), though it is rather likely that this also happens at other CMITs, in particular those engaging in open hardware project, such as the bionic hand developed at NW1, and who, therefore, share their designs with the rest of the world.

DC2.3–Engaging in Citizenship through Digital Technologies is defined as:

> To participate in society through the use of public and private digital services. To seek opportunities for self-empowerment and for participatory citizenship through appropriate digital technologies. (Ferrari, 2013)

Consequently, all the seven *entrepreneurial* CMITs aim to foster this skill. Yet, public events organised by CMIT members, such as the 'Design Nights' at C4, can also enable to directly

[17] `http://www.thingiverse.com`

foster DC2.3. Indirectly, even *non-entrepreneurial* CMITs can enable to foster this skill, as they help would be entrepreneurs and people willing to engage in citizenship develop their projects (through prototyping for instance).

Finally, there was no mentioning of activities helping foster *DC2.5–Netiquette* and *DC2.6–Managing Digital Identity*, but then, again, CMITs are physical environments where the importance of such skills is much lower, so this outcome is not particularly surprising.[18]

5.3.3 Digital Content Creation (DC3)

Because CMITs, just like any fab lab and makerspace, aim to make members engage with digital tools, they are highly instrumental in fostering *DC3–Digital Content Creation*. Whether as a part of projects or in classes, all CMITs enable to "develop digital content" [DC3.1] and "integrate and re-elaborate digital content" [DC3.2].

While programming is generally a skill needed to produce advanced technological products, the vast majority of the equipment at CMITs does not require such a skill (for instance, creating a 3D model can be done with a 'WYSIWYG' CAD software, which can also be used to modify the output of a 3D scan). Yet, nine of the CMITs—five of the *entrepreneurial* ones (C2, S1, C3, S2, NW1) and four of the *non-entrepreneurial* ones (C6, C5, NC2, NW2)—offer programming training. In this respect, C2 mentioned that "programming is now a skill which is important for entrepreneurs". Likewise, NW2 emphasised the need for advanced programming skills to foster actual technology entrepreneurship (and not just "copies of existing ideas").

Finally, while one could think that fab lab and makerspaces would be a good place to get acquainted with "copyright and licences" issues—especially considering that all members create digital content, which they generally end up distributing or sharing, only one CMIT, C6, explicitly mentioned tackling this issue in their CMIT activities. This is even more surprising, considering that C6 is a *non-entrepreneurial* CMIT. Instead, one would have rather expected *entrepreneurial* CMITs to foster this skill, as intellectual property management could be a vital expertise for start-ups and entrepreneurs. This unexpected result was one of the motivations behind organising a focus group, as we thought it may have been the case that this skill was indeed fostered, but did not appear explicitly in the list of activities carried out by the interviewees.

[18] Though, as a part of policy, CMITs and other fab labs and makerspaces may be a good environment to organise classes related to these two sets of skills.

5.3.4 Safety (DC4)

This set of skills includes: “protecting devices” (DC4.1), “protecting personal data and privacy” (DC4.2), “protecting health and well-being” (DC4.3) and “protecting the environment” (DC4.4). While DC4.3 is (partially) covered by all the CMITs (each member receives a health and safety training before being allowed to use the CMIT equipment), none of the other skills were mentioned—directly or indirectly—in the interviews. For DC4.1 and DC4.2, this may be due, again, to the fact that CMITs involve mainly ‘hands-on’, ‘offline’, activities (it is in fact often the case that a large part of the digital equipment—e.g. 3D printers, CNC routers, laser cutters—is not even connected to the Internet). However, considering that 3D printers, laser cutters and CNC routers do produce waste, we would have expected to see DC4.4 being part of the skills fostered at CMITs. This result was another motivation to conduct the focus group.

5.3.5 Problem Solving (DC5)

“Creatively using digital technologies” [DC5.3] is one of the ‘mission statements’ of all fab labs and makerspaces. Consequently, it is not surprising that all CMITs have activities—in fact, probably most of their activities—fostering this skill. Secondly, either through classes or projects, all CMITs have an objective to enable members to turn their ideas into reality, which requires to “identify needs and technological response” [DC5.2]. It is in fact particularly the case for fab labs and makerspaces, since the same need—manufacturing a particular object—can be done using different technologies, e.g. 3D printing, laser cutting, CNC routing.[19]

Furthermore, CMIT activities involve dealing with physical products, which means that technical problems are likely to take place (one just has to consider how often 3D printers fail to manufacture the object described in the 3D model file). Consequently “solving technical problems” [DC5.1] is one of the key skills fostered by all CMITs.

In contrast, *DC5.4–Identifying Digital Competence Gaps* was not explicitly or implicitly mentioned in the interviews, aside from one of the CMITs, C2, who mentioned that members themselves were organising their own master classes, based on competence gaps—whether their own or those identified in others.

[19] Depending on the technology used, the resulting object is likely to look quite different, but nonetheless fulfil the same need.

6 Focus group

The idea of completing the interview stage with a focus group emerged early in the research design. Indeed, we were looking for means to validate and complement the results obtained at interview stage. In order to do so, we first considered using online information offered by the CMITs, as well as brochures and documentation they may provide to actual and potential members. However, looking online for information, we found that very few CMITs provided information about their activities and programmes, and when they did, information made available was very limited (e.g. location of the CMITs, opening hours, a short global description). We also investigated social media, but likewise, although many CMITs have social media accounts, they mainly posted pictures, without providing significant information about activities carried out at their CMIT. Upon request, it appeared that detailed 'offline' information was generally not available either, and when it was available, descriptions were usually too short to infer the intended learning outcome. As a matter of fact, the CMITs we visited did not offer brochures or any other forms of documentation. Activities for the week were generally written on a whiteboard and updated in an *ad hoc* manner and information about activities and programmes were provided verbally to both current and would be members.[20]

Considering this lack of information, we decided to complement interviews with a focus group. As mentioned in Section 4, focus groups are often run after the interview stage, especially when a focus on a particular issue is needed. Carey (1994) defines a focus group as a semi-structured session with the purpose of collecting information on a precise topic, which is held in informal settings and is moderated. In brief, the aim of a focus group is to collect data via a group discussion created by the moderator (Morgan, 1996). Following the recommendation of Millward (1995) that the moderator of the focus group should be someone directly involved in the research project, one of the authors was moderating the discussion, while the second author was observing, taking notes and photographs of the focus group materials (e.g. Post-its, paperboard, whiteboard),[21] with the help of a research assistant. The focus group discussion was recorded and subsequently transcribed and coded.

As no particular guidelines (apart from the 40% of educational activities rule) was given to CMIT founders by the programme, participants in the focus group were asked to identify the

[20] In this respect, it is important to remember that the schedule at fab labs and makerspaces—this being particularly the case for the CMITs we visited—is often fluid, being generated bottom-up in an *ad hoc* manner by the CMIT members available at a particular point in time.

[21] As well as providing suggestions of questions to the moderator

skills that they deemed as the most important for the future (21^{st} century skills were not mentioned), as well as the activities carried out in their CMIT enabling to foster these skills.

First, participants were asked to write on Post-it notes the particular skills they considered important. The advantage of using Post-it notes is that they can be easily moved around to explore different ways to organise clusters (Cassell and Symon, 2012). Overall, 46 skills were identified by the participants (each participant supplying around five each).

Then, as displaying full data in one location aids valid analysis (Miles and Huberman, 1994), participants were asked to glue the Post-it notes on a board and to cluster them when possible. This first exercise enabled to identify nine skills:

A. Ability to plan (including time management)
B. Creative thinking
C. Ability to work in teams (including virtual ones)
D. Public speaking
E. Multidisciplinary thinking
F. Additive manufacturing (i.e. 3D printing)
G. Making (i.e. making things with hands)
H. Information search
I. Independent work (including self-education)

At a later stage (when discussing activities and skills), P8 suggested that another fundamental skill needed to be added: “into action”, i.e. the ability to actually implement an idea and to put it into practice. All the other participants agreed with this suggestion, as they felt that their CMIT was providing such a skill. Consequently, this 10 skill was added to the list:

J. Into action

F–Additive Manufacturing was the largest cluster (eight Post-it), followed by *C–Teamwork ability* (seven), *B–Creative Thinking* (six), *A–Ability to Plan* and *H–Information Search* (four Post-its each). The other skills clustered between two and three Post-its. Five skills previously identified (related, for instance, to language skills, robotics, experience of failure) were left aside by the participants because they felt they were not related enough to the clustered skills.

Interestingly, this first stage revealed some differences between *entrepreneurial* and *non-entrepreneurial* CMITs, as none of the latter indicated skills related to *A–Ability to Plan* and *J–*

Into Action.[22] Conversely, and perhaps more surprisingly, *non-entrepreneurial* CMITs were the only ones to identify *G–Making Things (with hands)* as an important skill for the future. The 10 participant—a representative of the Moscow Region Department of Innovation, overseeing the CMIT programme—identified overall five skills, four of which were related to the *F–Additive Manufacturing* cluster and one related to the *B–Creative Thinking* cluster. This is interesting, because the objectives of the policymaker appear narrower than what people who received the funding see as objectives.

In the second stage of the focus group, participants were asked to write down which of the identified skills their particular CMIT enabled to foster. They were also asked to single out, amongst them, skills they felt were not fostered by traditional education (Table 4).

Table 4: Skills fostered by the CMITs (* skills not taught in traditional education).

Skill	P1	P2	P3	P4	P5	P6	P7	P8	P9
A. Ability to plan	✓				✓*	✓	✓	✓	
B. Creative thinking	✓	✓	✓	✓	✓*	✓		✓	✓
C. Teamwork ability	✓	✓*	✓	✓	✓*	✓	✓	✓	✓
D. Public speaking	✓	✓*			✓*	✓	✓	✓	
E. Multidiscip. thinking	✓	✓*	✓	✓	✓*	✓		✓	✓*
F. Additive manuf.	✓*	✓	✓	✓*	✓*	✓	✓	✓	✓
G. Making	✓	✓	✓	✓*	✓*	✓	✓	✓	✓
H. Information search	✓		✓	✓	✓*	✓	✓	✓	✓
I. Independent work	✓	✓*	✓	✓	✓*	✓	✓	✓*	
J. Into action	✓	✓	✓	✓	✓*	✓	✓	✓	✓

Some of the results were expected—i.e. participants all singled out *F–Additive Manufacturing*, *G–Making*, *C–Teamwork*, *B-Creative Thinking*, *J–Into Action*, as skills fostered by the activities carried out in their CMIT, while eight out of nine also indicated *B–Creative Thinking*, *H–Information Search*, and *I–Independent Work* as part of these skills—and hereby confirmed what was observed during the interviews. *D–Public Speaking*, a part of skill *EC2.5–Mobilising others*, was pointed out by six of the participants (EC2.5 was present in the activities of 11 out of 13 CMITs interviewed, but contains other skills than public speaking).

What was more surprising was that *E–Multidisciplinary thinking*, which was not identified as a skill in the interviews (and is not explicitly one of the 21st century skills), was identified as a skill fostered by eight CMITs out of nine. Another surprise was that only five participants out of nine identified *A–Ability to Plan* as a skill developed at their CMIT. Even more surprising, three out of five of the *entrepreneurial* CMITs did not single out this particular skill, whereas it is very similar to skill *EC3.2–Planning and Management*, which was identified in the interviews as being carried out by nine out of 13 CMITs, including all the *entrepreneurial* ones. Yet,

[22] While this skill was identified at a later stage, two related Post-its were suggested at the beginning by two entrepreneurial CMITs.

amongst those three, two did not take part in the interview stage, so it is indeed possible that the activities of their CMITs do not foster this skill to a great extent. Another possible explanation is that *A–Ability to Plan* and *J–Into Action* might have appeared to participants as too closely related (e.g. one could consider A as being part of J), leading them to choose one over the other.

In a third stage, participants were asked to write on Post-it notes activities run at their CMIT. They then were asked to glue the notes on the board and to cluster them. Five main types of activities emerged from this exercise:

1. Courses (i.e. a series of scheduled classes)
2. Master classes (i.e. single events)
3. Projects
4. Competitions and hackathons
5. Collaborative projects with universities

This is, again, similar to the activities that were identified at the interview stage.

Table 5: Main skills fostered by types of activity carried out at CMITs.

Skill	Courses	Master classes	Projects	Competitions/ hackathons	Collaborative projects
A. Ability to plan				✓	
B. Creative thinking	✓		✓		
C. Teamwork ability			✓	✓	
D. Public speaking				✓	✓
E. Multidisciplinary thinking					
F. Additive manufacturing	✓		✓		✓
G. Making	✓			(✓)	
H. Information search	✓				
I. Independent work					
J. Into action			✓		

Participants were then asked, together as a group, to map activities with the main skills they provide, i.e. for which skills are the activities identified most instrumental (Table 5).[23] Courses were deemed most effective in fostering creative thinking [A], Additive Manufacturing [F], Making [G] and Information search [H].

Surprisingly, participants in the focus group declared that master classes were not particularly effective in developing any of those skills. They provided two reasons for that: 1) master classes typically focus on extending knowledge in a particular (and narrow) field, whereas the skills

[23] Because of time constraints, participants were not asked to carry out an exhaustive mapping.

identified are more transversal skills 2) master classes are also often used not to teach skills, but as a means to attract people to the CMITs, so are in fact ‘marketing’ events.

Projects were identified by the participants as being particularly conducive to Creative Thinking [B], Teamwork Ability [C], Additive Manufacturing [F] and Being into Action [J]. Participants noted that the vast majority of their projects related to the use of Additive Manufacturing/3D printing. There was an agreement that the impact of CMITs was particularly large in this respect because, although schools and universities are often equipped with 3D printers, their usage is often very controlled, by fear that the schoolchildren or students would break something. Instead, CMITs are much more open and do provide people with a far greater degree of freedom to use the tools as they want, which leads users to learn far more.

Competition and hackathons were singled out as providing ground for Abilities to Plan [A], Teamwork Abilities [C], Public Speaking [D]. Making [G] was also mentioned by some participants, but not all. Competitions and hackathons were also identified as a ‘marketing tool’ enabling to promote the CMITs. Finally, collaborative projects with universities were deemed instrumental in building up Teamwork Ability [C] and Additive Manufacturing skills [F].

It can be noted that two of the skills, *E–Multidisciplinary Thinking* and *I–Independent Work*, were not linked by the participants to any particular activity. Again, this does not mean that these skills are not provided, but, instead, that the activities listed were more instrumental in fostering other skills.

7 Discussion

The aim of this research was to investigate the role fab labs and makerspaces can play in fostering both entrepreneurial and digital 21st century skills. In this respect, the case of the CMIT fab labs and makerspaces proved rather insightful, and because of their (relative) homogeneity, enables some degree of generalisation.

In regard to entrepreneurial skills (EC1 to EC3), both the interviews and the focus group (logically) revealed differences, depending on whether fab labs and makerspaces consciously aim to promote entrepreneurial skills or not. In this respect, CMITs that do provide courses and classes to teach business skills, or put an emphasis on commercialisation in the projects run at the CMIT, are generally more effective in fostering entrepreneurial skills. Yet, this does not mean that fab labs and makerspaces that are not entrepreneurially minded do not deliver entrepreneurial skills at all. Indeed, activities organised at fab labs and makerspaces, because of their nature, foster organically a certain number of entrepreneurial 21st century skills, such as *creativity* [EC1.2], ability to *mobilise resources* [EC2.3], ability to *cope with uncertainty, ambiguity and risk* [EC3.3], ability to *work with others* [EC3.4], and ability to *learn through experience* [EC3.5]. Hence, at least a third of the 15 entrepreneurial 21st century skills identified in Bacigalupo et al. (2016) are naturally fostered by fab labs and makerspaces, regardless of their inclination towards entrepreneurship. Furthermore, interviews have revealed that other skills, such as the abilities to *mobilise others* [EC2.5] and *take initiatives* [EC3.1], as well as (perhaps to a lesser extent) *self-awareness and efficacy* [EC2.1], *motivation and perseverance*, and *planning and management* [EC3.2], are also likely to be fostered by all fab labs and makerspaces through their activities regardless of their entrepreneurial orientation.

Yet, there are skills, such as *financial and economic literacy* [EC2.4], *valuing ideas* [EC1.4] and, to some extent, *spotting opportunities* [EC1.1], which are unlikely to arise 'naturally' through the activities carried out at fab labs and makerspaces. Fostering these skills thus requires a conscious effort to do so, and, indeed, the interviews have revealed that only fab labs and makerspaces with an entrepreneurial focus can help foster all entrepreneurial 21st century skills, except perhaps one, *ethical and sustainable thinking* [EC1.5], which requires, in addition, that fab labs and makerspaces also put an emphasis on this type of issue in their activities.

Overall, the entrepreneurial 21st century skills naturally provided by fab labs and maker spaces are first and foremost *action* skills [EC3], then skills related to *resources* [EC2], and only finally skills related to *ideas and opportunities* [EC1], which tend not to be so well covered unless there is a clear entrepreneurial focus.

Interestingly, the focus group also revealed differences in the skills that are considered as important for the future, equally by entrepreneurially minded CMITs and those who are not, the former being more likely to see *ability to plan* and *creative thinking* as key skills for the future, with the latter putting a greater emphasis on *teamwork* and *making* things with hands.

In terms of entrepreneurial education, it is clear that fab labs and makerspaces can indeed be used as drivers for entrepreneurial skills, but that may only happen 'naturally' to a certain extent. This means that there may be a need to proactively engage fab labs and makerspaces in delivery activities that promote the development of entrepreneurial capabilities. However, it is rather clear from the interviews that the issue may not simply be a question of willingness, but also a question of capabilities. Indeed, even 'would-be' entrepreneurial fab labs and makerspaces may lack themselves the necessary skills. This was for instance the case of S1, who runs an incubator,[24] and even successful 'entrepreneurial CMITs', like C2, rely heavily on "external"

[24] Which is consistent with the literature, for instance M'Chirgui et al. (2015) show that incubators have to have skilful professionals, with different backgrounds, specialisations and experiences to be successful.

people (whether for training or mentoring) to help grow entrepreneurial skills. Consequently, the suggestion of C5 (a non-entrepreneurial CMIT) could be used as an inspiration to bolster entrepreneurial education:

> It would be really great to have a pool of people with particular competences, either business or technical, that the CMITs could use when needed. These people could be both from other CMITs and from the outside.

Thus, aside from very particular circumstances (e.g. the presence in the fab lab team of people with entrepreneurial and business skills, or an easy access to such people—for instance for fab labs and makerspaces located in university premises), asking fab labs and makerspaces to foster 21st century entrepreneurial skills may require the creation of a specific pool of resources they can draw from.

Logically, the difference between entrepreneurially minded and non-entrepreneurially minded fab labs and makerspaces is likely to be far less important in regard to fostering 21st century digital skills (DC1 to DC5). Through their activities, fab lab and makerspaces help develop skills related to *information and data literacy*, *digital content creation* and *problem solving*. They may also cover partially other skills, such as *collaborating through digital technologies* [DC2.4] and *protecting health and well-being*, but perhaps one of the rather surprising results of this study is that the fab labs and makerspaces possibly leave many of the 21st century digital skills, in particular related to *communication and collaboration* as well as *safety*, uncovered.

However, this may not, in fact, mean that fab labs and makerspaces are not particularly good at delivering digital skills for the 21st century, but instead that they deliver skills that were not beforehand envisaged as critical for the future. Indeed, makerspaces and fab labs provide a common ground between digital world and physical world. In this mixed environment, the skills they foster do not necessarily mean that digital technologies are central to the interaction and communication, as it is the case online. In such spaces, people interact, engage, share, and collaborate *around* digital technologies, not necessarily *through* them. Likewise, *safety*, as a concept, in such a mixed environment, is bound to be different from what prevails in a purely digital/online realm.

Consequently, being able to bridge the gap between digital and physical may well be one of the fundamental skills for the future. As a matter of fact, *additive manufacturing*, *making*, and *multidisciplinary thinking* were revealed in the focus group as critical skills for the future, and while the DigComp list of 21st century digital skills (Ferrari, 2013) established on behalf of the EU Commission was published recently, it is visible, especially in light of the present research, that it is based on a vision of 'purely online' digital technologies and does not encompass as yet the large changes in skill sets required by the advent and development of digital manufacturing. In this new environment, knowledge of electronics might become just as important as programming, and the ability to shape things with hands just as critical as designing virtual objects. And fab labs and makerspaces may well be just the key environment to fosters the new skills needed at the interface of digital and physical realms.

Conclusion

The objective of this research was to investigate the role that fab labs and makerspaces could play in fostering the skills needed for tomorrow, i.e. the 21st century skills, such as those identified in Ferrari (2013) and Bacigalupo et al. (2016). Using semi-structured interviews of founders of 13 fab labs and makerspaces and a focus group organised with nine fab labs/makerspace managers and a policymaker, we have provided reasonable ground to think that such spaces indeed can play a really important role in fostering skills—whether entrepreneurial or technical—needed for the future.

The main contribution of this research is twofold. In regard to entrepreneurial education research, as discussed in Section 1, recent literature has emphasised the potential of fab lab and makerspaces to help 'renew' entrepreneurship education and provide, outside of the classroom, a particularly critical 'hands-on' experience. This research has shown that this could indeed be the case, but only to some extent—while fab labs and makerspaces naturally foster some skills typically acknowledged as entrepreneurial skills, only such fab labs and makerspaces that have an explicit and proactive entrepreneurship education programme enable to foster the entire gamut of skills associated with entrepreneurship education.

In this respect, this research links back to the difference between the "narrow" and "wide" types of entrepreneurial education identified in the literature. While fab labs and makerspaces are likely to be naturally conducive of "wide" entrepreneurial education (i.e. focusing on making individuals more creative and innovative), "narrow" entrepreneurial education, which focuses on encouraging people to start their own business, is unlikely to happen naturally in fab labs and makerspaces and does require specific training and programmes to be devised. Yet, an important result of this research is to point out that the sole intent to deliver entrepreneurship education at fab labs and makerspaces may in fact not be sufficient. As illustrated in the case of several CMITs, despite their desire to deliver entrepreneurship education, fab labs and makerspaces might simply lack the competencies and resources to do so. Thus, it appears that the downside of this ‘out of the classroom’ mode of entrepreneurship education is, precisely, that. Being outside of the classroom may not enable to deliver a full scale “narrow” entrepreneurship education. Fab labs and makerspaces are unlikely to become the ‘silver bullet’ of entrepreneurship education, but instead an additional (albeit a very effective one) tool to foster entrepreneurial skills. Consequently, synergies between fab lab and makerspaces, on the one hand, and other vectors of entrepreneurship education, on the other hand, are critical. Yet, if we consider the “wide” view of entrepreneurship education, this study indicates that fab labs and makerspaces could indeed be highly effective tools to promote creativity and innovative skills.

Another issue highlighted in entrepreneurship education literature and discussed in Section 1, is that entrepreneurship education tends to have a lesser effect on the entrepreneurial intention of engineering students than it has on business students. This research shows that, though fab labs and makerspaces appear overall, in the “wide” way, to be effective vectors of entrepreneurial intent, it may well be the case that this is not enough to close ‘intent gap’ between engineering and business students. Indeed, as illustrated in this study, engineering students typically face a different trade-off between going ‘deep tech’ (i.e. fostering more advanced technical skills) and ‘going market’ (i.e. settling on standard technical skills and acquiring business competencies). Interestingly, this trade-off is reflected at the CMIT management level, with some CMITs promoting rather a ‘deep tech’ approach, and others a more ‘business’ approach.

On the practice side, a final, useful, contribution of this research to entrepreneurship education relates to pedagogy. Indeed, this study provides a mapping between key entrepreneurial skills and activities typically carried out at fab labs and makerspaces, hereby providing ‘how to’ guidelines to entrepreneurship educators and fab lab/makerspaces managers aiming to deliver entrepreneurial skills.

A second key contribution of this research relates to education related to digital skills, deemed as one of the most important aspects of 21st century skills. In this respect, this study shows that fab lab and makerspaces may indeed be effective in fostering such skills albeit to a limited extent. Yet, one important outcome of this research is that this limitation is not so much linked to a relatively poor effectiveness of such spaces to deliver 21st century technical skills, but instead that fab labs and makerspaces enable to develop skills that go beyond digital skills identified in 21st century skill frameworks. This is simply because these spaces are not just about digital technologies, but about ‘making’ technologies. Consequently, they may well not be the most suitable place to foster the whole range of 21st century digital skills, simply because they are (obviously) not purely online digital environment, but a mixed environment that combines digital and physical realms. Yet, the fact that fab labs and makerspaces go beyond what is generally thought as 21st century digital skills, and considering the foreseeable growing importance of digital manufacturing in the coming decades, makes it worth considering whether the ability to bridge the gap between digital and physical worlds should not be considered as a critical 21st century skill in its own right. In terms of contribution to practice (in particular in regard to education policy), this research might be a first step towards the definition of a new set of 21st century skills that move away from a purely digital and online environment to a world where objects while becoming digital still remain physical—as opposed to previous waves of digitisation, where objects, such as music, movies, books, pictures, could become entirely intangible—and competencies for both worlds have become critical.

Hence, overall, this research provides a better understanding of the role that fab labs and makerspaces can play in fostering both entrepreneurial and digital 21st century skills. Yet, it is, of course, not devoid of limitations. The first one is that the exploratory methodology used in this study, although it combines both interviews and a focus group, and is based on a large-scale *ex-ante* homogeneous network of fab lab and makerspaces, is less prone to generalisation than other kinds of methodologies. As a result, two obvious avenues for further research would be, on the one end to confirm the results of this exploratory research by surveying the 150+ CMITs that were not part of this initial study. Another limitation is that the fact that all the fab labs and makerspaces in the study belonged to the same country and were funded through the same programme, although it enables a better understanding of phenomena and enables a greater degree of generalisation, it may be prone to certain biases. Hence, a second avenue for further research would be to replicate this study across different countries in order to investigate whether the results observed in this research hold. A final limitation is that this research focuses on the 'educator' side, i.e. what skills in their opinion are fostered (or should be fostered) and through which means. As a complement, it would be interesting to investigate the 'user' side and see what skills users deem important, what skills they have been able to acquire, and through which means.

It has been now close to two decades since the first fab labs and makerspaces appeared. At a time when the number of such spaces is steadily growing and acquiring 'new' 21st century skills is deemed as increasingly important by policymakers, it is critical to understand the actual effect of such spaces in fostering skills for the new millennium. This research has provided a first thorough investigation of this question in relation to both entrepreneurial and digital skills. Half-digital, half-physical, theses spaces indeed provide large opportunities for new skill development. Yet, both on the entrepreneurial and on the digital side, their ability to foster such skills to a large extent is nonetheless closely linked with education policy. While such spaces have largely emerged 'on their own', explicitly targeted educational policies and programmes are undoubtedly required to make the most of these diamonds in the rough.

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