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Digital fabrication and Making with children:

Scrutinizing adult actors' strategies and challenges in mediating young people's activities

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ABSTRACT

Cultivating children's Maker mindset by facilitating their involvement in Makerspaces is recognized by researchers around the world as a topic worth investigating. Previous studies have revealed several different roles for the adults involved; however, there is little elaboration on the characteristics and strategies associated with these roles. This study focuses on digital fabrication and Making activities with children aged 7–17 (K12). It presents the results of interview data collected from nine adult actors analysed using nexus analytic concepts of interaction order and historical body as sensitizing devices. The results reveal the diverse strategies the adult actors employed as the mediators of children's learning, independent of their formal roles, when engaged with children. The study identifies numerous challenges the adult actors faced. Overall, it shows significant variety in the mediation of children's digital fabrication and Making activities, shaped by adult actors with different histories and backgrounds and within different contexts. The study includes the implications for the research and practice of digital fabrication and Making with children.

1. Introduction

The potential of digital fabrication and Making (DFM) in nurturing children's talents, creativity and science, technology, engineering and mathematics (STEM) skills is acknowledged by researchers around the world. Digital fabrication mainly occurs when a digital design created by a human using computer software is given to a machine that is controlled by a computer to produce a physical object. Digital fabrication is often associated with Making (Blikstein, 2013), that is, the creative production of artefacts in people's daily lives (Halverson & Sheridan, 2014). Digital design is usually at the heart of digital fabrication and together with Making facilitates both technology Making and Making using technology.

There is already an extensive body of literature addressing DFM activities with children taking place in formal, non-formal and informal learning contexts (Norouzi et al., 2019) categorized according to Eshach's framework (Eshach, 2007). Formal learning typically happens at school; it is guided by a teacher and is mandatory. Non-formal learning usually happens outside of school; it is guided and can be either voluntary or mandatory. Informal learning can happen anywhere; it is learner-led and completely voluntary. Based on the existing literature and framework, in the studies addressing DFM activities with children we found that particular attention is paid to the formal context of learning and the context of school (e.g., Berman et al., 2018; Chu et al., 2017; Giannakos & Jaccheri, 2018; Iversen et al., 2018; Mylonas et al., 2018; Otero & Blikstein, 2016). Studies of non-formal contexts, such as school libraries, mobile digital fabrication laboratories (mobile Fab Labs), universities, festivals and even schools (e.g. Alekh et al., 2018; Hamidi et al., 2017; Iivari & Kinnula, 2018; Iwata et al., 2019; Katterfeldt et al., 2018; Mori, 2017; Okundaye et al., 2018), and of informal contexts, such as libraries, Fab Labs, (smart) homes, museums and after-school centres (e.g. Kazemitabaar et al., 2017; Meintjes & Schelhowe, 2016; Romero & Lille, 2017; Sadka & Zuckerman, 2017; Voigt et al., 2019), have also been conducted. In the formal context, and sometimes also in the non-formal one, children's participation in the activities is mandatory (e.g. part of their school work (Berman et al., 2018)), while for the activities conducted in the informal context, their participation is mainly voluntary (e.g. after-school activities (Meintjes & Schelhowe, 2016)). Studies have identified a number of different stakeholders and their responsibilities in arranging DFM activities for children in these different contexts

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(e.g., Norouzi et al., 2019; Ventä-Olkkonen et al., 2019). However, studies comparing these different contexts are limited. Moreover, according to a recent literature review on the topic, many studies report experiences and success stories in DFM endeavours, while the challenges associated with such endeavours are not often reported (Norouzi et al., 2019). In addition, the current studies do not provide a nuanced picture of the complexities involved in DFM activities with children, such as issues related to participants' backgrounds and interactions, even though these things clearly affect what happens and what can happen in the activities (Kinnula & Iivari, 2019; Norouzi et al., 2019; Vossoughi et al., 2020; Wohlwend et al., 2017).

This study contributes by offering insights into the strategies the adult actors employ in the role of 'mediators for children's learning,' independent of their formal roles in the activities to engage the pupils. Moreover, we consider the context in which the activities take place and the background-related factors that might influence the strategies of the adult actors. We also explore the challenges the adult actors face while supporting children in DFM. Thus, our research responds to the call for further research by examining adult roles in different contexts (Dreessen & Schepers, 2018), considering Maker identities that teachers cultivate or develop by engaging in Fab Lab activities (Chan & Blikstein, 2018), providing further information on how to teach Making (Litts, 2015), elucidating the challenges of DFM endeavours (Norouzi et al., 2019) and further exploring the connection between facilitation and learning (Gutwill et al., 2015), which might help adults carry out different facilitation practices (Roque & Jain, 2018) in DFM activities with children. Our research questions are: *What kind of strategies do adult actors employ to mediate children's learning in digital fabrication and Making projects with children aged 7–17 (K-12) in different learning contexts? and What kind of challenges do they face?* To answer these questions, we analysed interview data from adult actors who arrange/facilitate DFM activities for children in different learning contexts. We use nexus analysis (Scollon & Scollon, 2004) as our research strategy and theoretical lens. Nexus analysis has been recommended to address complex topics in depth, taking into consideration a multitude of factors (e.g. Iivari et al., 2014; Molin-Juustila et al., 2015; Norouzi et al., 2019). It is therefore considered a suitable method for studying the complexities involved when adult actors mediate children's learning in DFM activities.

2. Related research: Adults' roles, interactions and activity contexts in DFM endeavours

Adults' involvement with children in digital technology design projects has been studied previously, and a variety of roles,[1] have been identified, such as researchers, designers, parents, caregivers, practitioners, teaching staff and support workers, with adult work focusing on facilitating children's work, motivating children, care-giving, acting as proxies for children, and co-designing with them (Benton & Johnson, 2015). In the DFM context, numerous studies related to DFM activities with children have been conducted. Different actors or stakeholders in that context have been identified, such as teachers, researchers, different domain experts, parents, facilitators, instructors, helpers, tutors and moderators, all having different responsibilities and roles in supporting children (e.g., Norouzi et al., 2019; Ventä-Olkkonen et al., 2019), similar to digital technology design projects more generally. These actors and their roles are not always the focus but are still mentioned in the papers. There are also studies that direct the reader's attention to the child–adult interaction and/or to the various roles of the adults who either arrange DFM activities for children or take part in the activities for some other reason (Chan & Blikstein, 2018; Dreessen & Schepers, 2018; Ejikeme & Okpala, 2017; Gutwill et al., 2015; Jones et al., 2019; Lee et al., 2018; Litts, 2015; Roque & Jain, 2018; Rosenfeld et al., 2019). These studies have zoomed in on the interactions among the participants and on role-taking, as we do in this study; therefore, they are discussed next.

Teachers are naturally central actors in DFM activities conducted in formal contexts, and their engagement as children's facilitators has been identified as relating to demonstrations with tangible objects, discussing prototype failure and managing behavioural issues (Chan & Blikstein, 2018). Attempts to develop teachers' skills for them to become Makers have also been reported, but the results show that the teachers did not identify themselves as Makers (Rosenfeld et al., 2019). Some studies have also discussed the roles of adult helpers in DFM activities with children. One study shows that facilitators played seven different roles in both front-stage and back-stage activities; they acted as facilitators, motivators, caregivers, proxies, co-designers, playmates and friends to children (Dreessen & Schepers, 2018). Different facilitative strategies for facilitator actors have been discussed in previous research, such as following the participants' lead while supporting them, treating each participant as a unique individual and creating the Makerspace environment (Lee et al., 2018). 'Spark, sustain, and deepen' are three facilitative strategies that have been identified, along with the exploration of their connection with the four learning dimensions of 'initiative and intentionality, social scaffolding and development of understanding' (Gutwill et al., 2015). Moreover, shifting of facilitators' roles has been identified as enabling them to support and guide the participants (Roque & Jain, 2018). Some studies also indicate that facilitators' identities and expertise play an important role in their facilitation styles and methods and eventually in shaping the Making experience (Jones et al., 2019; Litts, 2015), and even in limiting their abilities to support children in DFM activities (Litts, 2015). Parents have acted as facilitators as well, with their role shifting from helpers in traditional fabrication activities to help seekers in digital fabrication activities (Jones et al., 2019). Librarians have also been reported to play important roles in engaging children in utilizing libraries' Makerspace tools (Ejikeme & Okpala, 2017).

All the above-mentioned studies have investigated the roles of specific actors in a specific context, such as 'a teacher teaching DFM in school' or 'a facilitator facilitating DFM in a Fab Lab.' In this study, we instead bring attention to the naturally emerging activities and roles of different actors in DFM activities, independent of the formal positions of the adult actors, and to the strategies they employ in these activities. We also consider the context of the activities entailing either the mandatory or voluntary participation of children. In the studies exploring the roles of the adult actors, the reported contexts for DFM endeavours vary and are not always clearly stated. From our study point of view, it is of interest whether DFM activities are voluntary or mandatory for children. Considering the existing research on the roles of adult actors, a variety of contexts have been identified. In terms of the school context, the studies typically describe teachers' roles in mandatory DFM activities for children when the activities are integrated into the curriculum or into the students' school day (Chan & Blikstein, 2018; Rosenfeld et al., 2019). The less formal contexts vary, from separate Makerspaces (Jones et al., 2019; Lee et al., 2018; Litts, 2015; Roque & Jain, 2018) to Makerspaces in libraries (Ejikeme & Okpala, 2017), school Fab Labs (Chan & Blikstein, 2018), youth work premises (Dreessen & Schepers, 2018) and museums (Gutwill et al., 2015). DFM

[1] In line with (Kinnula et al., 2018) we define role as 'a behaviour pattern that can be socially expected but also subjectively defined', as defined by (Ickes & Knowles, 2012).

activities conducted in other locations, depending on how the activities are organized, can be considered to represent either non-formal or informal contexts with the voluntary (Dreessen & Schepers, 2018; Ejikeme & Okpala, 2017; Gutwill et al., 2015; Jones et al., 2019; Litts, 2015; Roque & Jain, 2018) or mandatory participation of children. For most of these studies that focus on interactions and the role taking of the adult participants, the context is informal with the voluntary participation of children, while in the current study we acknowledge both the voluntary and mandatory participation of children.

Our data-driven analysis led us to identify the role of 'a mediator of children's learning' among all the adult actors involved, adopted independently of the formal position of the adult actor or the formality of the learning context. In this position, the adult actors try to contribute to children's engagement and learning in DFM activities. 'Mediation' here entails interposing, effecting and transmitting an action as an intermediary (see (Mediate | definition of mediate by Merriam-Webster, 2020)). Focusing on the adopted strategies of different actors to engage children in this role enables us to offer a richer description of adult actors' activities compared to the previous studies.

3. Methodology

3.1. Theoretical lens

We use the qualitative research approach of 'nexus analysis' (Scollon & Scollon, 2004) as our research strategy and theoretical lens. Nexus analysis guides researchers to focus their interest on social action as the basic unit of the analysis (e.g. children engaging in DFM activities or adults facilitating children's DFM activities). The research strategy guides the researchers first to *engage* the nexus of practice by entering the community under study and looking for central social actions and related key actors. They then use various methods and collect and analyse data to *navigate* the nexus of practice. *Changing* the nexus of practice can be an intentional action in the research strategy, but it is also something that already happens when researchers participate in the practices, as their involvement itself can give rise to change (Scollon & Scollon, 2004). From the nexus analysis perspective, social action emerges in the intersection of three aspects—interaction order (IO), historical body (HB) and discourses in place (Scollon & Scollon, 2004). The concept of IO, originally coined by (Goffman, 1983), underscores that one should acknowledge that people interact in different ways when situated in different groupings. In any social action, one should consider the participants, the interactions among them and how these form and are constituted. HB (Scollon & Scollon, 2004), coined by (Nishida, 1958), refers to the accumulated life histories and experiences of people. These are highly significant in any social action, enabling certain kinds of actions while hindering others. The concept of discourses in place (Scollon & Scollon, 2004) is also significant, for example, the analysis of the different kinds of discourses about the social action in question. These three aspects can be seen as 'different angles of the social action under scrutiny' (Molin-Juustila et al., 2015).

In this study, we have chosen to follow (Molin-Juustila et al., 2015), who propose the concepts of HB and IO as useful tools to increase awareness of the issues affecting any social action. These concepts have proven to be valuable in making sense of complex topics; they enable acknowledging both the historical and social aspects involved in any social action (Scollon & Scollon, 2004) (see also, e.g., Iivari et al., 2014; Molin-Juustila et al., 2015; Norouzi et al., 2019). We therefore use these concepts for the theoretical examination of our data, leaving the analysis of discourses for future work. This allows us to focus our analysis on the practices of the actors. Overall, the nexus analytic concepts of HB and IO have been highly influential in shaping this study; they influenced the original selection of the research topic, the research design and data collection by focusing the interview questions asked, and they were used as sensitizing devices in the analysis of the collected data. Next, we elaborate on these issues.

3.2. Data gathering

This study is part of the navigating phase of a long-term research effort to understand the interactions of different actors in DFM activities with children, with the focus on the social action of adults facilitating children's DFM activities. We identified key actors in the local community of DFM both in formal (school) and non-formal/informal (Fab Lab at the university, DFM club) contexts through our previous collaborations. Two of the authors of the paper have over 10 years' experience collaborating with local schools and have knowledge of teachers and schools having a special interest in educating children in design and technology. The first author works in the university's Fab Lab and has (unofficially) observed adult actors' activities with children there, not only the Fab Lab instructors' activities but also the activities of teachers, including some of the teachers identified by the second and third authors via their connection with local schools involved in DFM activities. Interviews were eventually conducted with nine actors who were invited to participate in the study and who accepted the invitation.

To navigate the nexus of practice, we conducted the **interviews with the nine key actors** (seven men and two women aged 19–50; interview length 60–90 min; total of 9 h 53 min of recorded audio; three interviews at the school and six at the university) who engaged in DFM activities with children aged 7–17. The interviewees' educational backgrounds were in computer science, telecommunication engineering, music, teacher training, chemistry, physics, theology, English philology and software engineering. They had worked as teachers in junior high schools, researchers at universities or instructors and/or facilitators of DFM activities in Makerspaces. They had different levels of experience in working with children, ranging from very limited experience to 16 years of experience. Their experience in DFM varied from significant (six interviewees) to limited or no experience. They conducted a variety of activities with children, such as '2D designing+laser cutting', '2D designing+vinyl cutting', '3D designing+3D printing', 'electronics+programming', 'robotics' and 'traditional Making and crafts (mainly as post-activities to the digital fabrication activities)'. The interviewees talked mostly about their general experiences and not that much about a specific event/workshop/activity or about the specific ages of children participating in the activities.

The semi-structured interview questions were created based on a recent literature review (Norouzi et al., 2019) that explores empirical studies of DFM activities with children and maps which stakeholders are involved and what they do. Based on this, a wide range of themes connected with the nexus analytic concepts of IO and HB (Scollon & Scollon, 2004) were included. Moreover, our prior engagement with the interviewees helped in establishing a rapport with them and provided us leeway in asking follow-up questions (Turner, 2010). Our interview approach provided us focus yet allowed 'a degree of freedom and adaptability in getting information from the interviewee' (McNamara, 2009). The final interview themes were as follows: interviewee's background, experiences and expertise; overview of the activities: what happens, where, how often, who participates; tasks and responsibilities in different stages of the activities from planning to performance; strategies employed for supporting children; opinion on children's engagement in the activities; on what occasions children either ask for the interviewee's support or the

interviewee realizes that children need support and offers help; and what kinds of challenges the interviewee experiences while working with children and supporting them. All interviewees were provided with information about our research focus and gave informed consent before participating. At the end of the interview, we asked for feedback for our future studies.

3.3. Coding and data analysis

In the first phase of analysing the interview transcripts, we used NVIVO computer software for open coding (Khandkar, 2009), generating appropriate codes and adding new data from the other interviews. We also used the interview guide as a resource for getting started with the analysis. The analysis was done by generating the higher level (abstract) codes and by considering both our research focus and the main themes of the interview questions. Then new sub-categories for the codes were added based on the interviewees' responses. The generated codebook (word document) of several pages gave us a detailed and structured data model as a basis for narrowing the focus, for further analysis and for further integration of the themes. From the codebook, it was possible to see that the adult actors' interaction and role taking when working with children was a central issue.

In the next phase, the analysis focus was on how the adults organized themselves for social interactions with the children within the activities, that is, how they supported the children's learning. The concepts of IO and HB from nexus analysis were used as sensitizing devices to acquire a more in-depth understanding, as suggested by (Molin-Juustila et al., 2015). We focused our attention on different kinds of interactions among the adult actors and children, that is, what the adults said about how they interact with children when trying to support their learning, whether this was connected to what they actually did, what they expected to happen and what they were hoping for the children. To give an example of interwoven IO and HB occurrences in the data, one of the interviewees said that he prefers to have less responsibility in terms of the technical guidance of children. So, throughout our dataset we looked for mentions of those factors that caused this more passive role of the interviewees. This led us to link children's HB (in this case, expecting more technical instruction from the adults), adult's HB (in this case, lack of knowledge of DFM) and the physical material (in this case, communication barriers due to the physical arrangement of the tables) with how they affect the interviewees' ways of interacting with children, that is, IO between the actors, and how they resulted in the adults using strategies that did not require technical competence. As another example, as we were looking for the various background- and history-related factors pertaining to adult actors that seemed to be shaping DFM activities with children, we encountered a mention of an interviewee who told us how his childhood experiences with casual and nice teachers were enjoyable (HB) and how he wants to replicate that good feeling in his own behaviour with children (IO). This resulted in the use of a certain type of strategy associated with the emotional support of children. At the end, we realized that our findings are linked to three different strategies—supporting children in technical learning (facilitating the learning), emotional and social support of children (encouraging learning) and managing children's behavioural issues (orchestrating learning).

Three central findings emerged from this analysis: (1) an adult role as 'a mediator for children's learning' with three different forms (mentioned above) and associated strategies originating from the IO-related themes; (2) the significance of the adult actors' HB (backgrounds, current occupations, experiences, interests and reasons for their engagement) in how they work in the mediator role; and (3) challenges encountered when mediating children's learning in DFM activities, originating both from HB- and IO-related issues. For example, creating a relaxed atmosphere can be considered as offering emotional support for children, and thus it has been linked with the strategies for encouraging learning, as this category of strategies is specifically related to emotional support mediating learning. Similarly, the interviewee's memory of enjoyment of their hobby is an example of how HB can guide the actions of a person, affecting how they want to interact with other people. These could introduce challenges as well, as in our data an actor with moderate HB in DFM felt helpless in situations where more technical understanding was needed when mediating children's learning.

The analysis of this study was done by the first author. The plan for the analysis was presented to the other authors as the experts in both the field of study and the methodology. The results of each step of the analysis were then collaboratively discussed in several workshops to find a shared understanding. The first author delivered the findings in the form of a table or narrative that the second and third authors critically scrutinized by evaluating the coherence, understandability, comprehensiveness, interestingness and relevance of the findings.

4. Results

The adult actors employed different strategies relating to the IO established or the IO evolving between the different actors in their work with children when acting in the role of 'a mediator for children's learning'. Various IO- and HB-related challenges they encountered in the DFM activities with children were also identifiable from the data.[2]

4.1. The strategies of the adult actors in mediating children's learning

The analysis shows the adult actors in our data mediated children's learning by adopting the role of a mediator of children's learning in three focus areas – facilitating learning, encouraging learning and orchestrating learning – independent of their formal roles in relation to children's DFM activities. While playing the mediator role, the actors employed different strategies to engage children.

4.1.1. Facilitating learning

The first focus area for the mediator role, facilitating learning, emerged in the data not in a sense of using the formal, professional pedagogy but in a more informal sense entailing helping, triggering, shaping and improving children's learning. In our data, it mainly emerged when adults were providing children with technical support during ideation, design and digital fabrication activities by giving indirect input to the pupils and encouraging them to figure things out by themselves. One can say these actors facilitated learning, aligning with the spirit of the Maker movement and Making-based education and supporting individual initiative, trial and error, the do it yourself (DIY) strategy and peer collaboration. As these findings are tightly intertwined with DIY characteristics due to being human-centric – related to individuals' mindsets and activities – with digital technology as an enabler, they can be considered as digital DIY, which '*stands at*

[2] As the mandatory and voluntary participation of children was an important aspect in our study, when talking about the number of participants we use 'M' for those actors who supported children when children's participation was mandatory and 'V' for those actors who supported children when children's participation was voluntary. For example, (2M, 4V) means that the result is from six actors, two of which supported children when their participation was mandatory and four of which assisted children when they participated voluntarily.

the intersection of maker and hacker cultures, nourished in their turn by the DIY (Do-it-yourself) practices' (Locoro et al., 2017). Seven different strategies were used by the six actors in this area, as detailed in the following.

The first strategy was **DIY**. This strategy emphasizing learning by doing was employed by six actors (2M, 4V) with the aim of shaping pupils' activities without the direct aid of adults. For example, one adult actor said '*Even when they are in some kind of a problem situation, we first try that they solve the situation by themselves. If not, we try to give them some hints on how it could be solved before telling "okay, this is done like this"*'. The strategy of **advocating peer-peer help** by encouraging children to ask each other questions and then if necessary ask the adults was also identified, the aim of which was to deepen children's independent learning without the close supervision of adults (2M, 5V). For example, one adult actor said '*I got one of the members of the earlier team to help one of the introverted high schoolers to use the laser cutter*'. In the activities with a (digital) DIY mindset, direct support and detailed instructions from the experts are minimized and instead the help of peers can be highly influential in children's learning. The integration of peer collaboration in digital fabrication activities has shown possibilities for overcoming some of the complexities of the digital fabrication process (Hjorth et al., 2016) for the adult actors conducting the activities. Adults' roles in conducting peer collaboration also show in other forms, such as encouraging learning, which is explained in the next section. The strategy of **triggering the creativity of children** was used by some of the adult actors who utilized four major approaches to facilitate the creative processes of the pupils: (1) different brainstorming methods, such as mind mapping, to teach children how to think differently and how to have different points of views (1V); (2) using questions and probes to help the pupils focus on the critical concepts and understand the roots of the problems by themselves (3V); (3) giving children a variety of examples that they can integrate with their own ideas (3V); and (4) emphasizing bringing problem-solving skills into the heart of the activities to enable children to learn to think independently to overcome the challenges encountered (3V). One adult actor said '*Well, it's from the flourishing of the examples. So, I give them ideas that you can do this, you can do that, like plural of varieties that they can do. And the creativity comes from when they start to do it. So, they start to do it and few moments back they ask that "can I do this?" "Okay yes, you can"*'. Creativity by engaging in producing innovative artefacts is not only one of the characteristics of DIY practices (Locoro et al., 2017) but is also a significant factor that comes to the fore in maintaining children's engagement in ideation and in solving complex problems in the digital fabrication process (Voigt et al., 2019).

Furthermore, in the case of facing technical difficulties, the strategy of **giving children hints**, for example by posing questions, was aligned with the goal of enhancing children's independent learning by providing children with less direct solutions and detailed tutorials that were easy to follow but yet demanded children find things out by thinking for themselves (1M, 3V). For example, one adult actor said, '*Whenever the problem is "what part can we use", "what can I use to this", "is this battery good for that", to give a wide variety of hints that what to look for in which part, what is a good practice, what is not a good practice*'. In (digital) DIY activities there is an emphasis on doing things without the direct intervention of the experts (Locoro et al., 2017). In this vein, giving hints could be considered a sensible and moderate approach to providing children with technical help without pointing out the ultimate solution.

The strategy of **giving freedom** appeared in the form of either full freedom for children or some indirect monitoring with the purpose of letting children express themselves by taking autonomous actions (5V). For example, one adult actor said, '*That you have to do this job, it has to fill these... it has to work like this, it has to have these kinds of things in the final work and then we gave freedom how to do it to them. Just help if they are stuck*'. Giving children freedom and flexibility is emphasized as a constructive characteristic of digital fabrication activities when accompanied with thoughtful scaffolding of children's learning activities (Pitkänen et al., 2019). Three of our interviewees adopted the strategy of **guiding children to learn through trial and error** and teaching them that failure is always an option (3V). For example, one actor accomplished this by giving extra pieces to the children so that they would feel free to make mistakes. Because digital fabrication activities usually consist of iterative cycles in ideation, design, prototyping and Making activities, engaging in the cycle of 'trial and error' is highlighted as a valuable approach for children that enables improvements in their learning and in their projects (Blikstein, 2013; Smith et al., 2015). Finally, one of the actors put huge emphasis on **adaptive instructing** in the sense of taking into consideration young people's needs. He underscored putting himself in their shoes to be able to guide them accordingly and match his instructions to their needs (1V). For example, he said, '*So that's when I really started to put myself in their shoes and think like, okay so if I were the person that came here, what would I want to learn, what do I need help with. Stuff like that*'. In DFM activities, especially with young novice learners, a variety of unpredicted and complicated challenges might occur due to problems that are usually presented as ill-structured. Therefore, adaptive instructing enables the adults to consider children's knowledge, skills, learning environment and needs and accordingly adjust their tools and methods for instructing children.

Some of the adult actors actively guided the children, while some believed it was more useful to give the children space. The strategies described above affected the actors' ways of guiding the children. Some actors mostly provided the children with verbal guidance instead of practical guidance because they believe children should only be provided with hints that enable them to do their projects even initially by themselves. Some actors preferred to give ideas or show the children examples as a basis for personalizing/modifying, while some were concerned about the possibility of the children duplicating those ideas. Sometimes, these actors preferred showing the right ways of doing some tasks (e.g. soldering) especially when it came to the younger children (e.g. 9–10-year-olds). Some actors avoided providing the children with low-level practical guidance, like asking children to press buttons at certain times, while some told the children in detail what they needed to do, such as 'now, press this button'. All participants facilitating pupils' learning usually provided verbal guidance and let the children do their tasks by themselves. Moreover, in those situations where children avoided working with the machines (e.g. laser cutter, 3D printer or vinyl cutter), most of the actors tried to convince them by first engaging in conversation with them and then giving them some space, or they tried to ask the children's peers to help them.

4.1.2. Encouraging learning

The focus area of encouraging learning for the mediator role emerged in the data when adults were providing children with encouragement, emotional and social support and when maintaining their motivation and positive feelings during ideation, design and digital fabrication activities. We identified 11 strategies that almost all the actors employed to support and sustain the children's engagement. **Engaging in conversation with the children** that is not necessarily related to the topic to make a start and to be friendly was the most common strategy used (3M, 3V). For example, one adult actor said; '*In general many kids are curious, they would like to ask questions and when they see that you*

can create other dialogue with them, they feel more comfortable'. **Breaking the ice by talking about themselves, making jokes and laughing with the children** (3V) were also employed. For example, one adult actor said, '*At first some of the children were quite shy … I help them get started just by talking to them, making jokes and laughing with them*'. These two strategies are important to put the children at ease, particularly in relation to DFM activities that are organized in a new environment, such as a Fab Lab, and led by an adult who is unknown to the children. One strategy often brought up by the actors in this study was **providing the children with engaging examples** that are connected to their real lives and that are close to their culture, such as Lego, TV series, movie characters, Netflix and Spotify, and utilizing those examples to reveal the potential of DFM while establishing the children's engagement in it by arousing their interest (2M, 3V). For example, one adult actor said, '*Sometimes it's nice to provide examples that they understand, so try to use some - I don't know - some TV series that they like or some kind of a movie character […] for example for small kids it's easier to know what they like, what they could like more, what they could like less*'. From this point of view, the aim was specifically to encourage learning by arousing children's interest and engagement in the activity through examples related to things they are familiar with and enjoy. As DFM is usually a vague and unfamiliar practice for children, getting to know about the possibilities of DFM through real-life examples that are of interest to children and might be motivating for them is important. The examples created by the teachers could be good sources of encouragement for the pupils to create their own products (Baranauskas & Posada, 2017).

Encouraging children to ask lots of questions by letting them know that there are no stupid questions and by being patient listeners and showing approval were some other strategies (4V). In order to learn more in-depth in a DFM context, being an active participant is a key. One way to be active is to interact with the experts by asking questions. In DFM activities, there is a high possibility of not knowing lots of things and of facing challenges in trying to grasp how things work. Therefore, adults' behaviour might either encourage children to ask questions, regardless of how simple and basic the questions are, or discourage children from asking about even more complicated topics. Less common but yet significant strategies we identified related to the importance of adults having trust in children by **treating children as adults**, meaning teaching things to them in a different way than teachers usually do, and **building one's professional relationship with children based on trust** by overcoming the myth that suggests children are lazy and cannot be trusted (1M, 1V). It is shown that in DFM activities, 'autonomous work of children and taking initiatives improves their decision-making skills' (Norouzi et al., 2019). One of the factors that probably highly contributes to providing young people with autonomous and independent work conditions, which is essential in (digital) DIY practices, is treating them as adults and trusting them. In our data, **making sure that children had something to do with their hands** was mentioned as one strategy (1M, 1V). For example, one adult actor said, '*Working with hands…it helps to keep the motivation*'. The strategy of **task switching** to deal with children's boredom due to repetition or challenges was also employed (2V). One adult actor said, '*Maybe just get bored of the same task, having to continue on the same task so I'll assign something else to them and then bring them back to continue their work*'. Regarding these two latter strategies, we place the emphasis on the importance of the design phase (2D and 3D) in DFM activities, which might easily lead to the children becoming bored. Sitting at the computers for a long time and merely designing could be exhausting and boring for children; therefore, they need some fun and freshness. Adult actors should engage children in doing/making something with their hands, such as making 3D shapes with dough, and should define simple and quick design phases that immediately switch children's tasks to a non-design task, for example, laser cutting a prototype after each phase of design and assembling the prototype or decorating it to get inspired for further development, which again requires sitting at the computer and designing. Feeling good and having fun is important in this iterative and sometimes boring process. **Putting less experienced children next to the most experienced ones** in order to increase inspiration by exposing children to the successes achieved by other children (1V) was also utilized. For example, one adult actor said, '*so it's like you come people that you are surrounded with. So, I try to surround them with people who do something with electronics, and they absorb everything from there*'. The strategy of **connecting like-minded children** was also used by encouraging children to do things together for their further engagement in the activity as a group, which in some cases also helped improve the children's social skills (2M, 1V). For example, one adult actor said, '*I have been talking with the boys and their families that they should go together […] and now they smile together and hang out together and come here at their free time to build things together. That's really good and they always were lonely boys first […] they both were interested in technology*'. Some actors aimed at enhancing children's engagement through **group division,** such as splitting up the genders or different personalities to form heterogeneous groups, thus promoting interactivity within the groups and allowing the children to encourage each other's learning (2M, 2V). For example, one adult actor said, '*We wanted to have girl–boy groups and we wanted to have the groups so that there was sort of pupils in the groups who we knew that would work well*'. In line with the spirit of social and collaborative experiments in (digital) DIY activities (Locoro et al., 2017), the three latter strategies could be linked to the significance of children's collaborative work in DFM activities, considering the role of the adults in shaping peer collaboration to maintain the children's inspiration and enthusiasm for working in group(s) and to encourage their interest in DFM activities upon experiencing the enjoyment and good feeling of working in their favourite groups. Moreover, one actor believed it was necessary to initially **push children** a bit in order to help them to put aside their fears or shyness and eventually start touching the machines (1M). Our findings highlighted that novice learners of DFM activities, especially older children, might feel anxious about working with the machines, even when they receive detailed step-by-step instructions for operating the machines by themselves.

4.1.3. Orchestrating learning

When the actors took on the mediator role while focusing on orchestrating learning, they shaped the children's learning with some strategies connected to children's behaviour management, which, again, can be related to the pedagogical field but address limited aspects compared to the teacher role at school. Sometimes, mostly in the case of mandatory activities, some of the actors realized it was necessary to use their authority by giving children the feeling of being watched. Thus, the strategy of **keeping children on task** (2M, 2V) emerged. For example, one adult actor said '*I just want to make them feel that this is fun and educating […] they're not adults at least, because they ... every time you turn your back they want to take their phone and play some games or check Instagram etc. You have to keep an eye on them all the time*'. **Acting as an order keeper** who tries *'keeping children on track'* by checking on them and ensuring they were doing something (2M, 2V) was another strategy. For example, one adult actor said '*Of course it was this kind of facilitator and making sure that they don't get too much side-tracked. Because as we were talking here before quite many of them didn't, they weren't so motivated so*

tried to make sure that they keep to the plan'. Furthermore, three actors experienced being subordinate authorities in the class and therefore took the position of a **teacher-assistant** who cooperated with the primary authorities by '*providing students with some additional attention and instruction*' (3M). In our findings, DFM activities are usually designed to be learner-led, which provides children with freedom and independence; therefore, the adults' authority might seem to decrease.

4.2. Challenges as reported by the adult actors

In addition to the role of a mediator of children's learning and the associated strategies employed by the adult actors, various kinds of challenges were identifiable. **The children's lack of creativity** concerned some of the actors because they found it quite difficult to redirect the thinking paths of the children (1M, 3V). For example, one adult actor said '*There's new generation of kids that use those mobile technology so much that it takes time from basics so much. And that's really a shame because I think it also affects the imagination of the kids*'. Two actors faced challenges in guiding children who had difficulty in **getting started with abstract ideas**, possibly because of being used to being provided with lots of facilitation and instructions in the traditional school (2V). For example, one adult actor said '*I'd say three days or so they started to get the hang of it and the thought that "Okay well, maybe if I place a strap here and something that I can just put the strap like lock it into place with, maybe that would work" and then they start doing prototypes […] I'm not sure what causes the trend with the younger generation that abstract work is harder for them*'. **Freedom** and the lack of strict structure in the out-of-school setting might overwhelm children (2M, 2V). For example, one adult actor said '*And then the idea is that children should go out […] they should be more free, they should be able to lay down and have digital gadgets with them. And yeah, that's ... in practice there is a challenge when children get this freedom. They very easily get side-tracked*'. **The lack of independent problem-solving abilities** appeared as a challenge when children were expecting adults to provide solutions without making any considerable effort to figure things out by themselves (1M, 2V). For example, one adult actor said '*Solving problems by themselves was a really hard obstacle for some of the children because they hadn't done that sort of that stuff before*'. These four themes were closely linked to children's HB, which brought challenges for the adults in dealing with them.

Working with older children was more difficult for some of the actors (2M). For example, one adult actor said '*for small kids, since I have kid, it's easier to know what they like, what they could like more, what they could like less, but with older kids it's more difficult for me to find that. The paths to try to encourage them*'. For some of the actors, HB-related issues such as the **generation gap** brought up some obstacles in understanding the language of children (2M, 1V), for instance not being familiar with a specific cartoon character that children were talking about. For example, one adult actor said '*I'm not always surrounded by that age group so they come with words, with concepts, which I don't know*'. One challenge related specifically to schoolteachers' HBs seems to be the **fear of not knowing things** because of the rapid changes in technology and the lack of time to advance their DFM skills (2M). Therefore, they were uncertain about integrating DFM into their classrooms. Notably, due to their lack of skills, these adults were not comfortable helping children with design and DFM activities. For example, one adult actor said '*But in these activities sometimes kids come up with questions that you don't know how to answer so you need to find a question either yourself or together with the kids*'. Another issue was that the **physical arrangements** caused some problems, not only for the actors in their interaction with the children but also for the children in interacting with each other (1M, 2V). For instance, when the arrangement of the tables and the sitting order was in a row, the adults and children experienced difficulty having face-to-face conversations, and the interaction of the children was limited to only interacting with those who were sitting next to them, and sometimes it was difficult for them to hear or to follow each other properly.

Dealing with unmotivated and disengaged children was the most prominent challenge for most of the actors (4M, 3V). To give an illustration of what the actors struggled with, imagine a situation when children are not engaged, they do not listen to the adults and they run out of ideas. Even when they are given ideas, they do not accomplish the tasks given to them. They get side-tracked and even distract other children, and eventually at some point do nothing but sit and use their mobile phones. For example, one adult actor said '*When I guided them to do a specific task, they clearly said "no, we are not going to do that" […] if you explain and children don't listen, what can you do?*' Our interviewees reported about those moments when children did not want to engage in the activities; even the relatively exciting makerspace environment and the machines, even the 3D printers, did not motivate them. In some situations, the children did not listen to the actors who were trying to motivate them, even those orchestrating the learning, and the motivators failed to improve the children's engagement after trying different strategies. Therefore, the children were left alone to do whatever they wanted. Sometimes, **a project could** also **be really challenging** for children, which led them to experience some level of frustration or disappointment. Consequently, some children were angry or sad and even cried or became distracted by other activities, such as using their mobile phones. For example, one adult actor said '*For example, let's say that their code doesn't work. So instead of searching for answers on their own, like okay, there's this error code, what does it mean. They're just staring at it and thinking oh it doesn't work, and they just take their mobile phone*'.

4.3. Challenges regarding the strategies in different contexts

Issues with the strategies to facilitate children's learning in the mandatory context. Although digital fabrication activities might inherently have the potential for creativity due to the iterative rapid prototyping (Stephenson & Dow, 2014), it is not enough per se to deepen creativity. Therefore, the adult actors should take active roles in facilitating the creative thinking process of children. *Triggering the creativity of children* is a strategy that was not mentioned by the actors in our study in the mandatory participation context. *Trial and error* is another common approach that is relied on in digital fabrication activities where children learn from their own or others' failures (Smith et al., 2015), which leads to their deeper conceptual understanding of the topic. Children should have the chance to receive support from the adult actors, at least when they are about to start learning through trial and error. Nevertheless, based on our findings, in the mandatory context none of the actors encouraged the children to learn through trial and error. *Giving hints* is underlined as a mindful principle in co-making activities with children wherein the mentor patiently listens to the children and gives them gentle suggestions (Sadka & Zuckerman, 2017). Although giving hints might improve the learner's performance, independent learning and self-directed discovery, in our findings this strategy was neglected by most of the actors in the mandatory context.

Issues with the strategies to facilitate children's learning in the voluntary context. *Triggering the creativity of children* was a strategy used in the context of the voluntary participation of children by most of the actors. This was achieved by using different methods. However, only one teacher/actor mentioned the use of brainstorming and problem-solving methods to trigger

the children's creativity, although leveraging design thinking as a problem solving approach in digital fabrication for creative learning is emphasized (Smith et al., 2015).

Issues with the strategies to facilitate children's learning in both voluntary and mandatory contexts. *Adaptive instructing* might be an advantageous strategy for digital fabrication activities where the challenges encountered might exceed the predictable spectrum of challenges due to some characteristics of such activities, such as freedom, variety and autonomy. In our study, only one of the actors in the voluntary context mentioned the importance of flexibility and adjustability based on children's needs and feelings. In a literature review of practical studies of DFM activities with children, *giving freedom* is emphasized as an overwhelming benefit for children due to their lack of courage and experience in learning through free exploration (Norouzi et al., 2019). In our study, in the voluntary context all the adult actors mentioned giving freedom to children while facilitating their learning, although we did not find any hint of careful consideration in formulating children's freedom. The lack of such consideration might disturb the functioning or arrangement of the activities. Moreover, the actors in the mandatory context did not mention adopting the strategy of giving freedom to the children.

Issues with the strategies to encourage children's learning in the voluntary context. *Connecting like-minded children* is a strategy to motivate collaborative learning that was used only by one actor in the voluntary context. Children's collaboration is essential and might even have a significant effect on their attitude towards the activity (Sharma et al., 2019). Adults need to intervene and engage children in collaborative tasks in digital fabrication activities, which might require different considerations and forms of collaboration for different forms of digital fabrication activities. Motivating peer collaboration by merely connecting like-minded children or grouping children based on age would not be enough for digital fabrication activities, because to facilitate children's collaboration in each form of digital fabrication process a different setting for grouping children might be required.

Issues with the strategies to encourage children's learning in the mandatory context. *Task switching* is an important strategy that was not used by any of the actors in the mandatory context. In our study, this strategy was used in the voluntary context by two actors for the purpose of smoothing children's moods. Task switching is a strategy where the type of activity (the form of digital fabrication) is one of the factors that determines how the switch should occur to maintain the continuity and correlation among different tasks in relation to the aim of the activity and to maintain the mood of the young people engaging in the activity.

Issues with the strategies to encourage children's learning in both voluntary and mandatory contexts. Treating children as adults was an interesting way of interacting with children mentioned only by two actors in both voluntary and mandatory contexts. Treating children as adults could be considered a form of democratic empowerment, as discussed by (Kinnula & Iivari, 2019). It gives children the power of decision making that is enabled not only by the trust the adults place in the children's work but also by being aware of 'when, where and how much' to give decision making power to children. Making sure that children had something to do with their hands was also a strategy used only in two cases in both contexts. It was emphasized as an effective way to balance the design task, which sometimes might be boring and frustrating for children. Again, although making something with their hands could be refreshing for children, it would be more efficient if planned in line with the goal(s) of the activity in order to keep children engaged in refreshing, fun and creative ways of doing/making things with their hands that are not detached from the design activity (see, e.g. Nemorin, 2017). Implementing this strategy might be more effective when it is integrated in the design of task switching for activities in different kinds of digital fabrication.

Issues with the strategies to orchestrate children's learning in both voluntary and mandatory contexts. The strategies of keeping children on task and keeping the groups in order emerged as a challenge for the actors in both the voluntary and mandatory contexts. Due to the children's authority in DFM activities with a DIY style, in the mandatory context children could easily forget that their engagement in the activity is still necessary, while in the voluntary context they might totally disengage by putting aside the task and spending their time playing around. Taking strategic actions to orchestrate learning in DFM activities seems to be significant regardless of the context of the activity, which still might entail careful and distinct considerations for each learning context, considering who the adult authorities are, where the activity is taking place and what the purpose and leaning goals of the activity are. For example, non-teacher authorities, especially in the voluntary context, might face serious issues in orchestrating the learning, as children might easily ignore them.

4.4. The influence of the adult actors' historical body

Our data shows that the backgrounds of the actors clearly shaped their actions, indicating the influence of their HBs. Certain themes emerged from the data, such as childhood and adulthood experiences and interests, level of the experience in working with children, knowledge of working with children, level of technical knowledge, current occupation, previous work experiences, academic background, personal beliefs, personality (strengths and weaknesses), age difference or similarities and goals and reasons for the engagement. Our data also shows the versatility of the backgrounds that these adult actors have (see Table 1).

The adult actors reported various and differing pedagogical, promotional, personal and occupational reasons for their overall motivation to engage in DFM activities with children. These include doing one's job, self-improvement, training responsible Makers and future innovators, enhancing children's social and group work skills, helping children who are not doing well in traditional school to blossom, giving children the possibility of 'learning to learn,' giving children confidence by providing them with the chance to feel successful and attracting children to university majors, specifically engineering.

Some of the actors were hugely influenced by their impressions of people in their childhood or adulthood, such as having a father who is an engineer and being surrounded by different kinds of technology at home since childhood. They wanted to share the good feelings they received from their own instructors with the children and avoided providing the children with low-level instructions because they had received a high level of training. For example, one adult actor said '*When I was younger, working in the swimming school our own teachers were very casual and nice. And we had good time there, so I just want to spread that to the younger people*'. The data indicates that many other issues in the backgrounds of these actors are influential in addition to their formal education or current formal positions.

Our analysis also revealed that usually several of the HB-related themes weaved together and shaped the different strategies of each actor in assisting the children with DFM activities. This means it is possible to consider having several different scenarios for the actors' ways of doing things by blending their different HB-related themes. As an example, one actor – with teaching occupation, pedagogical study background, not enough skills and interest in DFM activities, and the occupational goal of

Table 1
Background of the adult actors.

Academic background	Work	Experience in working with children	DFM Skill	DFM context
Business, ICT (Information and Communication Technology), Pedagogy	Researcher	Senior level	Intermediate	Mandatory
ICT	Researcher, Fab Lab Instructor	Senior level	Advanced	Voluntary
Teacher Training	Technology Teacher	Senior level	Advanced	Voluntary
Teacher Training	Teacher of History, Social Studies, Religion, Psychology, Philosophy	Senior level	Inexperienced	Mandatory
English Philology	English Teacher	Mid-level	Inexperienced	Mandatory
Chemistry	Instructor of Electronics and Robotics Club	Mid-level	Advanced	Voluntary
ICT	Instructor of Electronics and Robotics Club	Mid-level	Advanced	Voluntary
Physics	Fab Lab Instructor	Entry level	Advanced	Mandatory
Music	Instructor of Electronics and Robotics Club	Entry level	Advanced	Voluntary

doing one's job – faced the challenge of providing the children with technical help and preferred to stick to their job as 'an order keeper' who tends to solve most of the issues by keeping the children on task. The actor said '*With a well-set plan I think we can also work as facilitators not maybe in instructing how to use the program because I don't know the software not at all but … yeah, in the pedagogical instruction we can take part in that […] It was just to keep them on their task to help them overcome their disappointment*'. However, a non-teacher actor – who was interested in working with children, did engage in the activity not only as an occupation but also out of the interest, had experience in DFM, was not experienced in working with children, and also had occupational and personal goals for the engagement – had difficulty facilitating the children's learning and engaging children in the activity. However, he was pretty flexible in supporting the children by actively switching the mediating style and employing different strategies to find a way to help the children. The actor said '*I was so used to working with skilful university students, but when it switched to non-experienced high school students, I had to put myself in their shoes and change my teaching process entirely*'.

When zooming in on the HBs of the teacher actors inexperienced in DFM, we found that their HBs influenced their choices and methods of mediating the children's learning. *In the mandatory context*, *teacher actors* with limited experience in DFM did not mention any of the strategies used for facilitating learning. In addition, for these actors, 'freedom and the lack of strict structure for the activity' and 'integrating DFM activities into their classroom' are two main challenges identified. The teacher actors in our study needed training for DFM activities due to their limited experience and lack of knowledge in DFM (HB). This was the main reason for shifting their role from facilitating learning to encouraging and/or orchestrating learning. Moreover, their occupation (HB) – being teachers and doing things in a structured way – and their personal and collective beliefs (HB) about the education system regarding the expectation that teachers know everything made these actors detached and unwilling to integrate DFM activities into their classroom.

However, *the teacher actors in the mandatory context* used only two strategies introduced in the category of encouraging learning—'engaging in conversation with the children' and 'group division'. Moreover, these teachers were associated with all the strategies in the category of orchestrating children's learning. Although the strategies introduced in 'encouraging learning' are mainly tied to the emotional support of the young people, having enough contextual knowledge in DFM (HB) was fundamental in the emergence of some of the strategies, as these kinds of support would be more influential when received from those who are actively supporting children. However, these teacher actors had more passive roles in the activities, as explained above. Training teachers in digital fabrication might take a long time (Milara et al., 2020), as would establishing their interests and reasons for their engagement when the activities are not tied to the curriculum. However, these teachers' academic backgrounds, knowledge of and experience in working with children (HB) helped to maintain their goals in deploying a few strategic actions to encourage children's learning. Additionally, their teaching occupation (HB) caused them to use more strategies for 'orchestrating learning' that were closely linked to their pedagogical field and method of managing the pupils' behaviour. All in all, these teachers' roles were not prominent in the DFM activities with children. As an example, we addressed the effect of the HBs of the teachers inexperienced in DFM in the mandatory context on their roles and ways of mediating children's learning. We will discuss our insights regarding the influence of the actors' HBs in role taking and strategy adoption in the different contexts of DFM activities with children.

5. Discussion

Making and DIY are suggested by (Grimme et al., 2014) as 'important areas of study within HCI because of their relative novelty and fluidity' and 'potentially transformative practices'. As suggested by (Dreessen & Schepers, 2018; Norouzi et al., 2019), in this work we studied adult actors with diverse backgrounds who work in formal, non-formal and informal contexts by zooming in on the mandatory and voluntary participation of children. As recommended by (Benton & Johnson, 2015; Norouzi et al., 2019), we contribute to the on-going discussion on the roles and responsibilities of adults by introducing the mediator role with three focus areas and a multitude of strategies relating to the complex IOs (Norouzi et al., 2019) that formed and evolved in the situations within DFM activities. To understand the nature of mediating children's DFM activities, we focused on the strategies the adult actors employed in three ways of mediating children's

learning—facilitating children's learning, encouraging children's learning and orchestrating children's learning. In the facilitation category, the adult actors focused on giving technical support and supporting children's learning in the spirit of the Maker Movement and Making-based education (see, e.g., Blikstein, 2013; Godhe et al., 2019). When encouraging children's learning, the focus was on emotional support and inspiration. When orchestrating children's learning, the focus was on maintaining order during the activity. Furthermore, we revealed several challenges the adult actors faced in DFM activities with the children, thus addressing the lack of research on the topic (Norouzi et al., 2019). We also scrutinized the status of the strategies in both the voluntary and mandatory contexts. The influence of the actors' HBs on the adopted roles and strategies was also explored.

5.1. Adult actors' work as a complex situational social process

It is noteworthy that the mediators' focus areas did not depend on the formal role of the actors. This is one of the novel findings of this study. So far, studies have focused on examining actors in particular formal positions (see (Chan & Blikstein, 2018; Dreessen & Schepers, 2018; Gutwill et al., 2015; Lee et al., 2018; Rosenfeld et al., 2019)), while this study elaborates on a role shared by the different actors. We revealed a lot of diversity in terms of the backgrounds, strategies and challenges of the adult actors in both the mandatory and voluntary contexts. We show that the adult actors hold various formal positions, ranging from teachers to different kinds of facilitators and instructors with divergent backgrounds and that they operate in different learning contexts in terms of formality. We show that the adult actors' backgrounds and the context shapes their activities with children and that adult actors with very different backgrounds were engaged in mandatory and voluntary contexts. That is, not just teachers were engaged in the mandatory context and not just technical facilitators were engaged in the voluntary one. This offers novel insights vis-à-vis the extant literature that usually focuses only on one particular group of professionals and their work practices and associated challenges (e.g., Milara et al., 2020; Pitkänen et al., 2019).

5.1.1. The influence of the actors' historical body and interaction order

The broad range of the identified strategies used by the adult actors while working with children in DFM activities was based on varying local circumstances and factors associated with the actors' backgrounds. By considering the different HB themes explored in this study, we argue that the actors' educational backgrounds and current professions are not the only significant issues shaping their strategies. We maintain that the mediator role, the focus area and strategy adoption constitute a complex social process highly dependent on the IO and HBs (Scollon & Scollon, 2004) of all the participants (also see, e.g., Yip et al., 2017 for the influence of the context, experience and participants on the interactions in the participatory design activities with children). Although the enhancement of creativity and confidence due to the autonomous work of children (Norouzi et al., 2019) and learning by trial and error in the exploratory learning (Rieman, 1996) and digital Making projects (Nemorin, 2017) are considered useful for children, sometimes it can be frightening for them (Norouzi et al., 2019). According to our findings, being provided with too general instructions, abstract thinking, learning via trial and error, ill-structured problem solving and autonomy in learning and doing are things that are missing in children's HBs but are demanded in DFM activities with a DIY style. This results in challenges for the adult actors.

In addition, the adult actors' HBs determine their ways of dealing (IO) with the above-mentioned issues, which originated from both the children's HBs and the adults' HBs. For example, the challenge of the fear of not knowing things, which is usually submerged in the HB of teachers, discourages them from taking active roles in facilitating children's learning in the immense world of DFM and prevents them from having the tendency of developing the maker identity. This finding is in line with (Chan & Blikstein, 2018) (see Jones et al., 2019; Litts, 2015 for extended discussions on Maker identity). As a result, their IO changes by switching from their roles in facilitating children's learning to mainly orchestrating children's learning and occasionally encouraging children's learning. As we showed in our findings, even encouraging children's learning entails having relatively active roles in guiding children in DFM activities, which is tied to the actors' knowledge and skills in DFM, among the other possible factors. To help teachers take a more active role in DFM, including using their pedagogical expertise, teachers should be actively supported in their own learning of DFM (Pitkänen et al., 2019).

However, although behaviour management to maintain children's positive behaviour (Benton & Johnson, 2015), which usually enforces engaging in the activities (Norouzi et al., 2019), has been reported in the literature, our findings revealed considerable ineffective actions of non-teacher participants in switching to their mediator role of orchestrating learning. Lack of training in how to behave with children in different circumstances, especially when they need emotional support (HB), and lack of authority in children's autonomous DFM activities (IO) result in the non-teacher actors having difficulty dealing with disengaged and problematic children. Moreover, because the non-teacher actors usually do not know children well enough (HB), it is critical to build an informal rapport with the pupils (IO) to help them feel comfortable participating in the sessions (Benton & Johnson, 2015). Despite revealing some influencing factors in the non-teacher actors fulfilling the mediator role, a clearer understanding of the reasons for these specific ways of supporting children is needed in future studies.

5.1.2. The influence of the context

Regarding the context of the activities, it has been found that motivation tends to be more extrinsic in formal contexts, mainly intrinsic in informal contexts and may be extrinsic in non-formal contexts but is typically more intrinsic (Eshach, 2007). Based on our findings, the children were initially excited to be in the out-of-school setting (voluntarily or not) and to do something not school-like. However, it is not always enough to engage them in activities. Therefore, children's engagement in an activity is not inherent to their voluntary participation, especially taking into account the variety of unpredicted technical challenges they might face due to the broad range of activities in DFM processes that even the technical helpers might find difficult. In terms of context, our findings bring to light the problematic situation with the strategies in the three forms of mediating children's learning.

In the mandatory context, some fundamental strategies (triggering creativity, encouraging trial and error, giving hints and giving freedom) linked to the idea of learner-led discovery, which is an important characteristic in DFM activities with DIY style, were missing in facilitating the children's learning. Moreover, in terms of encouraging the children's learning, the strategies of task switching, giving children something to do with their hands with the purpose of lightening their mood and treating children as adults were neglected. We believe that the nature, structure, limitations and HBs of the actors (both adults and children) in the context of the mandatory participation of children are some of the factors that left little room for the adult actors to give priority to engaging in enhancing children's creativity; encouraging trial and error; giving hints instead of active instructions; task switching, including doing something with the hands; giving freedom; and

treating children as adults to give them the power of decision making for independent learning. These strategies are essential in conducting DFM activities with children, as we showed in our findings. Regarding these characteristics in DFM activities with children, we refer to the discussion on creativity in (Stephenson & Dow, 2014), the discussion on the importance of trial and error in (Smith et al., 2015), the discussion about giving hints as a mindful principle in (Sadka & Zuckerman, 2017) and the discussion on treating children as adults as a form of democratic empowerment in (Kinnula & Iivari, 2019). In addition, due to the limitations of the activities conducted in the mandatory context, children are usually provided with limited themes of DFM examples, which might constrain their insights regarding the possibilities of DFM. Moreover, orchestrating children's learning and dealing with children's behavioural issues and their disengagement are still challenging in the mandatory context, although children's behaviour should be responsive to certain expectations. We relate this to the 'autonomy' characteristic of DFM activities, which children are not used to due to the school system (HB). In addition, experienced adults in the mandatory context are usually unfamiliar with guiding children in open and learner-led learning discovery (HB); also considering our previous discussion on the influence of the actors' HBs and IO.

In the voluntary context, facilitating children's learning and triggering children's creativity is a hot topic. Problem-solving methods are largely ignored, although they are strongly emphasized in DFM activities (Smith et al., 2015). Enhancing the creative contribution of the children while they are building technical skills is one of the factors that might lead to a more prolonged impact (Benton & Johnson, 2015). Our findings reveal that, on one hand, the importance of creativity in DFM is not highlighted for the adult actors mediating children's learning during an activity, especially in the mandatory context. On the other hand, backstage planning for the creative engagement of children in the activities is almost missing for reasons such as lack of time, lack of knowledge and skills to leverage it and context or activity limitations. Providing example ideas to guide children's initial idea generation and inspiration during design sessions is essential (Benton & Johnson, 2015). However, according to our findings elaboration on how the examples are provided is missing, which is a critical loss, as there are many ways to provide children with examples that might be understandable or vague and that might trigger or constrain creativity. Although linking the provided examples to children's lives, needs and interests is an effective strategy to begin with, it might not be enough to maintain their engagement in DFM activities. This is especially true in the voluntary context when the possibilities of doing things or thinking of what is possible to do are enormous. Therefore, suitable examples provided by the adult actors depending on the context, form and phase of the activity are important and contribute to both facilitating and encouraging children's learning. Furthermore, giving freedom to children is a state-of-the-art trend in DFM activities. However, how to formulate children's freedom is missing from adult actors' DFM work with children. Formulating children's freedom it is essential and lack of it might overwhelm children with the given freedom (Norouzi et al., 2019). It also brings challenges for the adult actors in terms of controlling disorderly children who might try to make the most of the freedom given them. Even switching to orchestrated learning might not be effective, especially when the non-teacher actors are the authorities and try to take control. Therefore, to overcome these issues and to deepen children's learning by engaging them in pleasant learning experiences where they have good feelings and are eager to learn, more emphasis must be placed on strategies in the form of encouraging learning in the voluntary context. A highlighted strategy to adopt in this category is forming groups, as children's collaboration might have a significant effect on their attitude towards the activity (Sharma et al., 2019). However, the non-teacher actors' unfamiliarity with the participating children and with the best practices for encouraging children's collaboration (HB) makes it challenging for them to decide how to form the groups. Teacher actors' lack of DFM knowledge in certain subject areas (HB) confront them to the challenge of grouping children; because, each form of DFM process might demand different considerations to facilitate children's collaboration. These considerations can be applied by those actors who are experienced and have sufficient technical knowledge and skill in DFM.

5.2. Insights for CCI practitioners

Previous research has highlighted the need for further consideration of how to teach Making (Litts, 2015) and the need to better understand how facilitation and learning are connected (Gutwill et al., 2015). It is important to inspire children to have a smooth start in DFM, which is essential for their learning and might even be useful in gaining children's trust in the effectiveness of the adult's role, which is important for their long-term participation according to (Norouzi et al., 2019). We have taken a step in to this direction by making visible different strategies adult actors used in our study to mediate children's learning, particularly when facing various challenges (see also Roque & Jain, 2018). The strategies are not necessarily unknown to the practitioners, but this study may be the first to make them visible by articulating them. This enables other practitioners to reflect on their own work practices and to potentially develop them. Therefore, we suggest Child–Computer Interaction (CCI) practitioners consider whether different mediation strategy categories could be useful for them to conceptualize and better plan their work with children. Likewise, we suggest considering whether the challenges the adult actors in our study encountered when supporting children could occur in their future work and whether the strategies used to engage children when facing the challenges were useful. The insights should be useful for CCI practitioners interested in working with children in DFM in particular, as well as when collaborating with children in general. Many of the findings are not DFM-specific despite relating to a DFM context.

The three categories for mediating children's learning in DFM activities – facilitating children's learning, encouraging children's learning and orchestrating children's learning – can be used in different phases of working with children. We suggest that adult actors consider all three viewpoints when planning activities and during activities. Even though the strategies can be utilized in many kinds of CCI activities, what is unique to DFM is working with physical materials, particularly machines. Therefore, the suggestions below have been largely devised based on the nature of DFM. Design work with complex software, working with electronics, understanding how materials behave and using machines in often noisy environments are all specific features of DFM, and they should be kept in mind when reading the suggestions below. They also follow Maker pedagogy more generally—encouraging problem solving, DIY, working together and learning from others and creating personally meaningful objects (see e.g., Blikstein, 2013; Godhe et al., 2019). Note that the age of children naturally affects how the guidance below is put into practice.

From the perspective of facilitating learning:

- Planning the whole process from a learner-cantered perspective: considering children's existing knowledge or lack of it and their (learning) goals and needs.
- Supporting a DIY attitude in children: carefully consider in advance which activities children are able to do on their own (with good instructions and adult support in the form of practical help and guiding questions when needed) and which activities they need adult help with. Adults can help when children try something for the first time (such as using the machines, trying software), and the next time the children can do it independently. This is supported by giving children clear goals for their work and providing materials and tutorials that are easy to follow but still inspiring.
- Arranging activities so that peer collaboration and peer learning are natural characteristics of the activities
- Planning beforehand both the methods and materials used to trigger children's creativity in different phases of the activities so that they support the work; preparing examples that serve various needs and phases of the work.
- Planning trial and error consciously in the process and supportive discussions, for example, by showing an example of failure when demonstrating something to children and then discussing the reasons for the failure, trying again and achieving success or by giving children a 'safe' possibility to try and fail and try again.
- Planning phases in the working process where children are aware of the goals and have freedom to work on their own towards the goal, with a certain amount of indirect monitoring.

From the perspective of encouraging learning:

- Connecting the work and instructions with children's own lifeworld by using examples close to children's own culture (toys, movies, memes, etc.).
- Creating a positive and easy-going atmosphere by discussing and making jokes with children about topics other than the activities, which might encourage them to ask questions when they need help.
- Giving children space to do their work and not guiding them too much; treating children as human beings and trusting that they do what they are supposed to do, yet still pushing them delicately and only a bit when they need to overcome, for example, a fear of working with machines.
- Exploiting group work with careful consideration of how to group children: like-minded children working together, and less experienced children learning from more experienced children and consider the ages of the group members and the different views of the genders.
- Being prepared beforehand for how to handle boredom due to repetition, waiting time for using the machines or (too) challenging work: task switching, tasks to do when waiting and planning tasks for different levels of difficulty.

From the perspective of orchestrating learning:

- Considering beforehand suitable strategies for how to maintain order in the activities, for example, by sharing duties between adults (somebody checking that children do what they are supposed to do), devising rules for mobile phone or computer use, not running in the premises or when leaving the room is allowed.
- Discussing the rules beforehand with teachers or parents if they are present so that they can help maintain order if necessary.

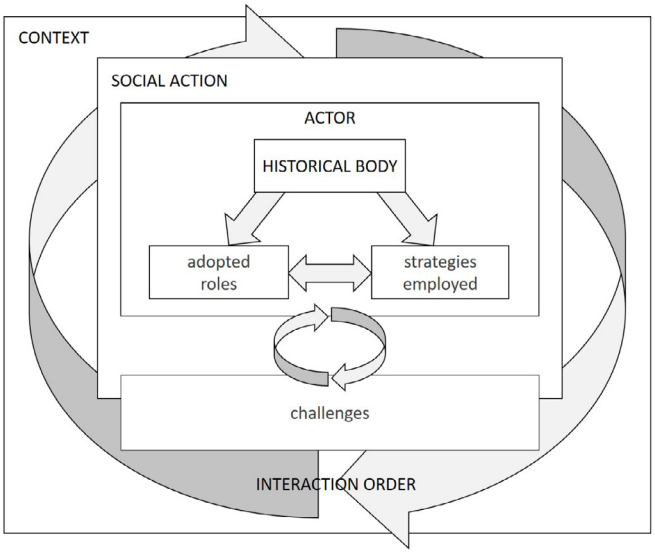

Fig. 1. Conceptual understanding of the social action of adults mediating children's DFM activities.

- Discussing the rules beforehand with the children and explaining why such rules have been devised, as the safety of everybody present must be considered; this supports the development of a safety culture in DFM (Rajanen & Rajanen, 2019).

We also want to complement this practical guidance with a more theoretical perspective of DFM with children to make it possible for researchers and practitioners to take an in-depth look at their own practices. The nexus analytic concepts of HB and IO focus our attention on 1) the context and backgrounds of the actors and how they shape the mediation strategies, 2) the interaction between the participants in DFM activities. The challenges the adult actors face and the strategies they choose in DFM could be explained by the IOs established or the IOs that evolved between the participants or by the HBs of some participant groups. In Fig. 1, we illustrate a more conceptual understanding of how a social action – in this case, adults mediating children's DFM activities – is dependent on its context and how the challenges (adult) actors face can be related to the social action itself, the context of the social action or the different actors and HBs and the IO between the actors within that social action in that particular context. The roles the adult actors or indeed any actor are able to adopt and the strategies they are able to employ in those roles are dependent on their own HBs, the challenges, the social action and its context and the IO between all actors. In the case of this paper, we have discussed the role of the mediator in children's learning, but the role could be any role any actor adopts in the DFM process.

Hence, we claim that for CCI practitioners planning to work with children in general and for DFM in particular, it is critical to ask:

- What is the **social action** and what are the limitations and requirements it sets? Are children there on a voluntary basis or are the activities mandatory for them (children coming to a library makerspace after school voluntarily to work on their own projects or children coming to a Fab Lab as part of their mandatory schoolwork)?
- What is the **context** (Fab Lab, Makerspace, museum, school classroom)? Does it set limitations and requirements for the social action and the actors (e.g. continuous noise of the

machines in a Fab Lab)? What does it afford (e.g. seeing examples of projects done by somebody else, triggering imagination)? What is the physical space like? Does it set the scene somehow, limit the activities or allow new and interesting IO to open (e.g., children sitting in a row when working together vs. around a round table)?
- Who are the **actors** in this social action (both adults and children) and participating in the activities? What kind of HBs do they bring into the activities? How does it affect the things that could happen? What kind of background knowledge, skills and education do they have? What is their level of agency in this social action and context? (see (Barendregt et al., 2018)). Consider 'Who participates with Whom in What' (Barendregt et al., 2018); that is, are adults entering the children's world or are the children entering the adults' world, and what follows from that?
- What kind of **roles** for the (adult) actors might be suitable in this context and with these participants?
- What are the possible **challenges** and how can they be mitigated?
- Which **strategies** might be useful when encountering the challenges and when mediating children's learning?
- How are the interactions, roles, and strategies different in **the context of various forms of digital fabrication process** (e.g. 2D or 3D designing, electronics work, programming, working with different machines, etc.)?

We strongly encourage DFM researchers and practitioners to consider these factors to gain an in-depth understanding of their own work.

6. Conclusions

With this study, we contribute to the knowledge base by introducing the role of mediator for children's learning and related focus areas and strategies of the adult actors arranging DFM activities. We offer novel insights by showing that the role, focus areas and strategies are adopted relatively independent of the formal position of the actor. We reveal versatility in terms of contexts and the adult actors involved. We show that the adult actors working in voluntary and/or mandatory contexts have different backgrounds, life histories and motivations that shape their strategies and choices, many probably unconsciously. Although the contexts set some limits and boundary conditions for their work, the adult actors also have a lot of freedom to plan and accomplish their work with children. We need to be aware of this versatility in terms of contexts and actors involved. The adult actors are recommended to take a self-reflective stance towards their work and to consider how their personal backgrounds, motivations, preferences and the context-sensitive factors are intermingled in their engagement with children.

We also underscore that the identified strategies are highly context-sensitive, demanding occasional role and/or strategy switching depending on the situation. We agree with some of our interviewees who believe in flexibility, as there is usually no single recipe for instructing and interacting with children because each child, each group and each activity is different. Therefore, the adult actors need to be knowledgeable and aware of both the value of their presence and the possible influence (both constructive and destructive) of their roles and strategies on children's engagement and learning. In dealing with different children, the adult actors must also be knowledgeable about different possible strategies and challenges and must be flexible and adapt by taking on different roles and using different strategies for different settings. We expect that all the strategies identified in this study are useful, but we acknowledge that in a different setting with different challenges and adult actors with different backgrounds some other strategies might fit better. The challenges our study revealed were partly independent of the context, but the challenges were especially visible in the case of the mandatory participation of children.

Regarding the limitations of this exploratory study, we had only nine interviewees from one city. However, within our informants there was a lot of variety in terms of their backgrounds, jobs and contexts of the activities. This helps in getting a wider understanding on the DFM practice. We wish to emphasize that some of the strategies and challenges we identified are not specific to DFM activities with children, but they are relevant for teachers and CCI practitioners working with children on a variety of topics. We also saw that many of the strategies and challenges are related to DFM activities in particular, that is, the strategies and challenges relating to (digital) DIY and DFM machines and tools. Regarding possible avenues for future research, we suggest CCI researchers further explore the roles of the adult actors engaged in DFM activities with children of different ages in different contexts (informal, non-formal, formal; voluntary, mandatory; with neurotypically developed children, children with special needs) and the different kinds of strategies the actors employ (in different forms of digital fabrication process), their possible motives for using those strategies and the identities that emerge among these adult actors. We also suggest scrutinizing the motivations of the participating children and how to help the adult actors keep children engaged.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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