International Journal of Child-Computer Interaction 29 (2021) 100303

Contents lists available at ScienceDirect

International Journal of Child-Computer Interaction

journal homepage: www.elsevier.com/locate/ijcci

Opinion paper

The show must go on! Strategies for making and makerspaces during pandemic

Marianne Kinnula [a,*], Iván Sánchez Milara [b,c], Behnaz Norouzi [a,c], Sumita Sharma [a], Netta Iivari [a]

[a] INTERACT Research Unit, University of Oulu, Finland
[b] Center for Ubiquitous Computing, University of Oulu, Finland
[c] Fab Lab Oulu, University of Oulu, Finland

ARTICLE INFO

Article history:
Received 15 February 2021
Received in revised form 1 April 2021
Accepted 1 April 2021
Available online 15 April 2021

Keywords:
Children
Teacher training
Formal/non-formal/informal technology education
Makerspace
Fab lab
Digital fabrication
Making
Design
Online education
Family collaboration
Pandemic
COVID-19
Online data collection

ABSTRACT

The COVID-19 pandemic is challenging for Fab Labs and makerspaces where the use of digital fabrication machines and working with physical materials in collaboration with others are at the heart of the activities. We have been actively promoting children's technology education both by training local teachers and by working with children themselves. The restrictions have resulted in limiting the number of participants or moving to online working, or even closing the workspaces and cancelling the events. To continue our work, we needed to explore new solutions for the situation. We have provided online training for teachers, experimented with working in family groups and fully online, while access to the digital fabrication machines and children's engagement in online activities were the largest challenges we encountered. We report in this paper our experiences with different solutions as well as challenges we have faced, both as regards technology education of children and collecting research data related to that.

1. Introduction

When COVID-19 entered our lives in spring 2020, the restrictions that followed caused many challenges in the education and everyday life of children and adults alike (e.g., Iivari et al., 2020; Antle & Frauenberger, 2020). Schools switched to a remote mode in an eyeblink, teachers were struggling to develop their teaching practices to meet the needs of this new normalcy, and parents had to enable and ensure online learning of their children, sometimes with limited resources, skills and competences (Adnan & Anwar, 2020; Andrew et al., 2020; Dong et al., 2020; Flack et al., 2020; Iivari et al., 2020). In addition to schools, there are other organizations and actors involved in children's education, such as makerspaces or after school clubs. By those actors, valuable non-formal and informal learning experiences are offered for children also in the field of technology education (e.g., Tisza et al., 2020), which entails different kinds of computer, programming, robotics, and making clubs, events, and spaces (e.g., Tisza et al., 2020; Kinnula et al., 2020). We have a long-term interest in children's technology education and have been teaching children design, making, and digital fabrication skills in both formal education context as well as in informal/non-formal contexts for over ten years (see e.g. Kuure et al., 2010; Iivari et al., 2014; Iivari & Kinnula, 2016; Tisza et al., 2020; Kinnula et al., 2020; Norouzi et al., 2021), arguing for children's genuine participation and empowerment in and through digital technology development (Kinnula & Iivari, 2021).

Some of the most relevant actors in the field of technology education are makerspaces and fab labs. Makerspaces are "informal sites for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products." (Sheridan et al., 2014). Fab labs form a global network of makerspaces, which share a common brand and a standardized set of processes and digital fabrication machines (Stacey, 2014). This facilitates the exchange of knowledge within the network: an object fabricated in one of the fab labs can be replicated in other

* Corresponding author.
E-mail address: marianne.kinnula@oulu.fi (M. Kinnula).

https://doi.org/10.1016/j.ijcci.2021.100303

fab labs. Standard tools used in fab labs are digital fabrication machines, i.e., such machines that are able to produce a physical object from a software model designed in a CAD (Computer Aided Design) application using additive of manufacturing processes; examples of those machines are a laser cutter, a vinyl cutter, or a 3D printer. Driving force behind both spaces is their community members, who share their expertise and knowledge and have a common interest in do-it-yourself activities. Makerspaces and fab labs all around the world have faced the challenge of engaging children in technology education due to the restrictions caused by the pandemic (e.g. Jayathirtha et al., 2020) and have had to figure out new ways and means to do that. This paper explores such endeavours, carried out by the University of Oulu Fab Lab (see e.g. Kinnula et al., 2020) and the City of Oulu Fab Lab, in Oulu, Finland (called "Oulu Fab Labs" from now on).

The University Fab Lab regularly hosts student and teacher visitors from local schools as part of a local strategy to educate children and their teachers as well as to potentially attract the students to study in the university in the future (see also Kinnula et al., 2020). Before the COVID-19 outbreak, activities were planned for the rest of the spring semester in the University Fab Lab: lectures, guided face-to-face tutorials, and project work, which generally entail lots of team collaboration. Due to the COVID-19, Oulu Fab Labs faced many restrictions that include limitations in the number of participants in workshops and other education events, obligation of keeping social distance in such events, closure of the workspaces in more extreme situations, and changing face-to-face events into online courses and even cancelling them.

Changing into an online mode is a big challenge in fab labs as use of the digital fabrication machines and face-to-face interaction in a makerspace are central in making: first, aligned with the spirit of maker identity and culture, spontaneous interactions and collaborations among peers are essential (e.g., Hatch, 2014) and promoted (e.g. Blikstein, 2013), and second, working with materials and tools is inherent to making; hence, there is relatively little to do without those (see also Iivari & Kinnula, 2018 on materiality and making). With novice learners, the presence and detailed guidance of an experienced instructor is also necessary, as the digital fabrication machines should be used correctly to prevent damage to them as well as to maintain safety of the machine users (see e.g. Rajanen & Rajanen, 2020 on safety culture in the context of digital fabrication).

Overall, because of the COVID-19 restrictions, the teachers/instructors in Oulu Fab Labs had to quickly adapt to the sudden new changes by making changes to the existing learning materials and embracing alternative pedagogical methods. This resulted in a high workload for the teachers/instructors. We also had an ongoing research project with data collection plans in the City of Oulu Fab Lab, and we needed to adjust our plans for that project as well. After the initial shock subsided, we started to implement solutions to cope with the new situation, by considering both the education and research data collection aspects. In the following sections, we discuss those solutions as well as the associated challenges we faced.

The paper is structured as follows. In Section 2, we discuss the opportunities and challenges in the case of full lockdown, in which case we moved to a fully online teaching mode. In Section 3, we discuss the opportunities and challenges encountered with a hybrid teaching mode. In Section 4, we elaborate on our experiences involved with teaching the teachers to teach children, while in Section 5 we discuss issues involved with supporting children and families. In Section 6 we present challenges and opportunities involved in research data collection based on our own experiences with conducting our project during the pandemic. Section 7 concludes the paper.

2. Full lockdown with fully online teaching mode — challenges and opportunities

At the start of the pandemic, both fab labs in Oulu were quickly closed, and we had to consider alternative ways for inviting children and teachers into the activities. Online context has been introduced as a context for making activities among the other contexts such as labs, hacker spaces, fairs, workshops etc. (Silver, 2009). As everything around the world was transformed into the online working mode, we also considered working with children online. Many challenges were identifiable along the way however, while we also identify issues that have worked well.

2.1. Supporting 3D design work

Tutorials and guidance available for online 3D design work. Many of the fab lab processes start with a design phase with a CAD software or a programming environment. Providing online training for how to use software for creating 2D or 3D models, circuit diagrams, and coding IDEs (integrated development environments) etc. is not new, and those are such activities that fit well in the remote learning methodologies. The maker community has produced a lot of tutorials that are a regular source for knowledge acquisition to many self-learners, both the learners and instructors alike, when they want to learn new techniques, solve problems, or get ideas for new projects.

Availability of 3D design tools. Even if during the pandemic digital inequalities have been exacerbated around the world (Adnan & Anwar, 2020; Andrew et al., 2020; Dong et al., 2020; Engzell et al., 2020; Flack et al., 2020), in Finland children usually have access to computers (see e.g. Iivari et al., 2020). Hence, this has not been a big issue in our case. Moreover, as most of the software used at the Oulu Fab Labs is free and open source, children can download them for free. In general, it is possible to find a free substitute for any needed software. Some software (especially advanced CAD design tools) requires a considerable amount of computational power that is not available on standard laptops or computers. However, this is the case only for a minority of the software we use, and that software can always be substituted by something less demanding, by overlooking some of the advanced (and generally more professional) features. Nowadays, many design software can be even run online without any installation. For instance, for online CAD design we can use Tinkercad (www.tinkercad.com) or Onshape (https://www.onshape.com/en/). The only software that requires a paid license is the one necessary to generate G-Code (language utilized to control automated machines) or to operate and calibrate the digital fabrication machines. This software is used at the last stage of the design and Making process, when utilizing those machines, which means it needs to be placed in the computers in the Fab Lab. Therefore, the children do not need to install it in their own computers. Thus, in the initial phase of working, this is not a problem.

Supporting online 3D design work. In formal education, schoolchildren working at their school computers could receive support and guidance from their schoolteachers, and in non-formal education, children could get help from other adults, for example their parents at home. Screensharing and requesting or giving remote control of the screen, that is available in most of the online videoconference platforms, could be used for instructing and advising. However, despite the opportunities many challenges can be identified in online 3D design work of children. First of all, getting started with design software, especially 3D design software, as well as seeking for help online can be a significant barrier for children (Hudson et al., 2018). Learning a new software is challenging; it requires entering a new environment where user's existing knowledge does not apply (Lafreniere & Grossman, 2018). On top of that, the online environment is very different from children's familiar face-to-face learning practices. Moreover, the level of experience with computers, the interface, similar software and domain knowledge can all affect learning of software use (Hudson et al., 2016). Lack of appropriate instructions in learning a new software can also be problematic (Rieman, 1996). The involved adults can experience a lot of pressure and a huge workload when trying to provide children with detailed instructions to get started with learning the basics and principles of a new software in the online learning environment, particularly with younger children (e.g., 7-year-olds). One challenge is also that the videoconferencing tools (such as Microsoft Teams or Zoom) are primarily designed for adults and are thus not necessarily so easy to use by children (Constantin et al., 2021).

2.2. Lack of access to digital fabrication equipment

With restricted access to the makerspaces, perhaps the biggest challenge in teaching digital fabrication to children is operating the digital fabrication machines after creating the software model. Although the machines are more and more affordable, they cannot yet be considered as consumer electronics devices, and hence, we cannot expect them to be available in most of the schools or in children's or teachers' homes. Hence, if children and teachers cannot access the fab lab premises, they most likely cannot operate the machines and hence fabricate objects. Therefore, we had to find alternative solutions. Fab Foundation offers a set of projects that can be done at home without the use of digital fabrication machines such as a laser cutter, a 3D printer or a vinyl cutter (https://www.scopesdf.org/covid-19/). In addition to that, we identified two potential solutions for cases without direct access to digital fabrication machinery: controlling the digital fabrication machines remotely and learning to use the machines through virtual reality (VR) simulation.

Remote control of digital fabrication machines. All machines in the Oulu Fab Labs are controlled by computers. Hence, it is possible to control those machines by remote controlling the attached computers. In addition to that, cameras are needed to see the status of the machines. For some tasks, however, presence of a human operator in the working space is still needed; for example, adding the stock material for laser cutting, removing the 3D printed piece before starting a new print job, and loading/unloading sheet of material for vinyl cutting. With this kind of arrangement, children would not follow precisely the same steps as they usually do in the Fab Lab; however, at the end, they would have a real product that could be picked up from the Fab Lab. We have tried this setup at the University Fab Lab, with relative success, with a CNC (computer numerical control) precision milling machine. This machine uses a milling bit to carve in a stock of material (e.g. wood) a 3D model previous defined in software. We have used this machine to remotely carve 3D models out of mechanical wax, and we are planning to try this out also with other digital fabrication processes and machines, for instance PCB (printed circuit boards) milling manufacturing and 3D printing.

The main disadvantage of this solution is the need of a human operator in-site. The operator should be able to do the required manual operations and ensure the machine is working correctly. The operator should observe the machine carefully for the hazards that might possibly happen due to malfunctioning (e.g., fire). Communication between the in-site operator and the remote learners might be challenging, especially if several learners are utilizing different digital fabrication machines, and the operator must keep track of all of them. In addition, the operator must keep a communication channel open with all remote learners, for instance, to confirm to them that the machine is ready to be utilized after the calibration.

One of the advantages of remote controlling of the digital fabrication machines, however, is solving the challenges of time needed for some digital fabrication processes; for example, the current 3D printers often require a significant amount of time to print an object of a reasonable size (Shewbridge et al., 2014). Thus, the waiting time for the 3D printers to create an object is one of the issues that usually frustrates children. Even when we have assigned children other tasks to do during the waiting time, they usually have not been able to concentrate on something else. Instead, they often stay around the 3D printer, watching how it works and constantly asking when it will finish the job. Remote working with 3D printers and not being around the printer might help reduce children's frustration.

Simulating digital fabrication machine operation in VR. We have not yet tested the idea of simulating machine operation in VR, but we are working with that. A good VR model should have a realistic 3D model of the machine, including a faithful emulation of the user interface to operate the machine and a realistic emulation of the machine's basic functionalities. The learners should follow the same steps in the virtual environment to operate the machine as they would do in real life. This might include also possible risks; for example, risk of fire with a laser cutter, or risk of being hurt badly if you do not operate the CNC router (a machine able to carve big stock of materials, for instance, to create pieces of furniture) keeping adequate safety distance. Creating the needed 3D models and the virtual environment require a lot of time and resources, however. We are currently building basic models for some of the digital fabrication machines, but recreation of the whole Fab Lab environment will require a huge amount of time. An obvious problem with a VR solution is also that you do not get a product out of the process and the materialization of the design in the physical form is one of the key aspects of digital fabrication. The VR solution might still be useful for learning to execute the digital fabrication processes safely, even without close observation of a fab lab instructor.

2.3. Digital fabrication challenges in remote teaching mode

Challenges with teaching large groups online. We have realized that remote teaching has more challenges than face-to-face teaching, especially with large groups. Most of our digital fabrication classes are normally scaffolded using small hands-on activities in which the learners need to solve problems by using digital fabrication methods and tools. This usually requires immediate feedback from the teachers/instructors in order to guide the learners to the right path when they are not utilizing adequate digital fabrication processes. In face-to-face teaching, it is easy to track the work of the learners just by having a look to their computer screen, even watching multiple computers at the same time. This is almost impossible in online teaching, even when the learners share their screens with their teachers/instructors. We have been changing from one learner to another (or one group to another), asking them to present their screen. This is not an efficient method with many learners in the class. Hence, we had to change the methodology; the learners were positioned as the ones who had to ask questions when they were not able to continue further by themselves. However, this situation can also be problematic because the learners do not take initiative for asking questions.

Difficulties in tracking the state of children's work. In relation to the previous point, we tend to have a very individualized tracking of the students in the University Fab Lab. Most of the education activities follow project-based learning pedagogy, with learners solving problems. Following this methodology, it is necessary to track learners' progress in order to give timely feedback if the planned solutions are out of the scope or the learners do not know how to continue. Usually, when the activity happens in the face-to-face mode, the teachers/instructors see the development of many student projects in parallel. However, in remote teaching, the teachers/instructors need to define some tutoring hours where each team can present their progress.

Remote working related challenges for children. Remote education has been mainly utilized in the past with adults. Children (especially younger ones) generally have not been familiar with it. We found children having difficulties in following instructions online, especially when concentration was needed during long working sessions. Our recommendation for the duration of an online digital fabrication or making session is approximately 40 min. Another issue is that the online environment demands children's active participation and automatically shifts the setting towards student-centred learning. When teachers/instructors' feedback to children is based on children's presentation instead of teachers/instructors' visual observation of the situation, children need to be able to reflect on what they have done prior their presentation. It can be challenging for children to monitor and reflect on their own performance, however (Hudson et al., 2018). Children did not also always realize their need to seek help in our projects, and as the concept of digital fabrication is relatively new to most of the children, they also faced challenges in formulating their questions due to lack of terminology. Formulating questions is mentioned as one of the main challenges for children in 3D modelling as well (Chilana et al., 2018).

3. Partly opening with hybrid teaching mode

In autumn 2020, the situation in Finland was so calm that it was possible to open the Fab Labs for working. Both Oulu Fab Labs permitted access with strict restrictions. We developed a hybrid teaching approach in which teaching of design software and principles for controlling the digital fabrication machines was done remotely, while the students could come to the Fab Lab if they wanted to fabricate something. We created strict rules for the Fab Lab access:

- Only two students and one Fab Lab instructor could be present at the same time. We moved some of the machines to a nearby room so we could have simultaneously four students in our premises.
- Hygienic measures should be respected at any time inside the Fab Lab premises: washing hands before accessing the premises, cleaning the machine controllers and computer keyboards after use using alcohol swipes, and keeping two metres of distance between any person in the Fab Lab.
- Fab Lab machines should be booked beforehand. No free access was allowed.
- Usage of computers in the Fab Lab was not allowed for design purposes. Therefore, the users had to prepare their design files and send them to an instructor to check and ensure the files were correct and ready for the machine use in the Fab Lab.

There were limitations in this approach, however. The setup works with a restricted number of participants, but it prevents face-to-face group work and makerspace community support. A supportive social context for making and collaborative work in digital fabrication activities is often important for achieving success in the projects, and the social aspect of digital fabrication and making activities is emphasized in the literature (e.g., Vossoughi & Bevan, 2014; Grimme et al., 2014; Lee et al., 2017; Okerlund & Wilson, 2019). The Fab Labs were only accessible to operate the machines and with many restrictions without actual social interaction. Nevertheless, we feel we managed to create a good intermediate solution in the middle of the crisis.

4. Training teachers to instruct children — tips and tricks

We have had difficulties recently to recruit participants for the different online workshops we have organized at the University Fab Lab. Even though online courses offer more flexibility and save time as there is no need to move to the workshop space, the number of participants in the workshops has been going considerably down. Our target group is mainly teachers who can take the role of a facilitator and act as a proxy for instructors, similar to Constantin et al.'s (2021) approach to designing online with children during the pandemic. We assume that teachers' level of stress and fatigue caused by the pandemic is one of the reasons why they have not been so keen on doing any extra activity outside their teaching duties. We are exploring new solutions to organize teaching activities to continue teacher training, hoping that the new forms of learning would be both more appealing as well as helpful to them.

We continue to opt for the hybrid learning with teachers. We are planning and running online workshops where we present different fab lab processes to the educators utilizing specific themes (Halloween, Father's Day, Mask fabrication …). The idea is to provide teachers with ideas for their classes and to introduce the usage of key software and digital fabrication machines to them so that they can then use those with children. These activities are planned as a 3-step process, where the teachers learn something new in every step:

1. We provide teachers with a video tutorial together with all design files are used in the tutorial. In the video tutorials (max. 10 min) we teach one digital fabrication process, use of the needed software, and use of the corresponding digital fabrication machine.
2. We provide the teachers an online workshop teaching the same process. The idea of this workshop is to have a feedback channel with the educators where they can ask questions while they are performing the tasks.
3. We lend equipment to schools and provide support to use them. Currently some of the schools need to come to the Fab Lab because they do not have adequate digital fabrication machines in their premises. We offer lending some portable equipment (e.g., small 3D printers, vinyl cutters or even laser cutters) and providing the schools with one-to-one training to use the equipment (either online or face-to-face). If teachers have any doubts about using the equipment, they can ask a fab lab instructor either via videoconference or in a face-to-face meeting. If necessary, an instructor can be present to support the teacher when they are using the equipment with children.

5. Supporting children and parents working at home — challenges and opportunities

Experimenting with remote support for children and their parents at home. One possibility is to work with family groups where parents, acting as proxies, support children's work, as is oftentimes the case also with online schooling during the pandemic (Goagoses et al., 2020; Antle & Frauenberger, 2020). Participation of parents as collaborators or proxy-instructors is a valuable opportunity for continuing the digital fabrication and making education. Fabricating some electronics circuits and embedded programming are common activities done with children and there are many commercially available kits with several online tutorials to choose from. We are considering providing similar kits to our learners with a basic set of electronic components, cables, and basic measurement equipment so that they can start to build electronics at home, supported with remote teaching. The idea is that the components can be easily brought together, preferably without soldering, for example by utilizing breadboards. Although we are opting mainly for commercially available kits, such as e.g. BBC MicroBit or Arduino, we are also considering fabricating some microcontroller boards and sensor/actuator modules by ourselves in our fab lab. Those could be distributed to local schools, or even fabricated by the schools themselves if they have the needed tools for that.

Challenges with remote support for children and their parents at home. We have encountered some challenges concerning authority and power dynamics, where the parent takes over for the child (Constantin et al., 2021, Antle & Frauenberger, 2020). For instance, in our project, a 7-year-old child participant was not able to comfortably work with the online setting and follow the instructor's guidance remotely. Therefore, his father was mainly in charge of communicating with the instructor and making the wire connections of the robot, based on the instructor's detailed guidance. The child was totally disengaged from the activity and had no idea what was happening. Moreover, working with family groups can also be time consuming for the organizers. For instance, a family engaged in a remote training session, as their making project was left unfinished due to the COVID-19 restrictions. Preparing for a one-hour online session with the family took a couple of hours of the instructor's time when the session activity was very specific and predefined. Therefore, when organizing online activities for children at home, the activity should be limited, structured, and tested by the instructor beforehand. In order to be able to instruct a large group of children working at their homes, children cannot be allowed to freely choose what they would like to make. This is because many unpredicted problems, not solvable for the instructors remotely, can occur during the session, and consequently the situation would get out of control. This would result in children experiencing failure without having a chance to achieve success, which could be discouraging (Buehler et al., 2015). Thus, one of the great disadvantages of remote instruction is the necessity to restrict children's creative freedom and opportunities for decision-making, which are important values for children's empowerment in digital fabrication and making.

6. Research data collection — challenges and opportunities

The challenges in organizing the activities are one thing and another one is how to collect research data in the situation. Some of our challenges were specifically digital fabrication and making related while some of them were more generally related to collecting qualitative research data.

How to find research participants. Recruiting research participants is usually a challenge even in typical situations, with the pandemic adding its own set of complexities (Constantin et al., 2021). We considered working with family groups as one way to work more safely during the pandemic. However, participating children, and/or their parents, might not be comfortable with online-only or hybrid sessions. With online-sessions, participating families need to create a working space in the home environment, which in the context of digital fabrication work means more than just sitting in front of the computer on the dining table, as various software, hardware, and other tools could be required. Thus, there is an overhead in setting up before any online session, unless the sessions are specifically for interviews, surveys, or discussion for data collection. With hybrid mode, where participants complete the design work online and visit the fab lab premises for using the digital fabrication machines, parents might not agree to visit the fab lab as they could prefer to limit their child's exposure to other persons outside of their essential networks, such as schooling. Or then, given the changing situation with the pandemic, various restrictions can be enforced city-wide or a need for social distancing can appear, greatly affecting the scheduling for physical Fab Lab visits. With such uncertainty always looming at the back of their minds, parents might prefer not to start new activities for their child during the pandemic.

However, there can be a positive effect as well. With the cancellation of many after school large-group activities, parents might be interested in seeking out alternative after school activities that are conducted in small groups or with family groups, to continue their child's learning and development beyond formal education. In our case, we had this experience, where more participants and families answered our recruitment ad than we were able to accommodate. Recruitment was done through personal networks of the researchers and with schoolteachers at an International School, who announced the opportunity through the school's online system for parents and students. Since the sessions were held in English, which is not usually the case for such long-term studies in Finland, many immigrant families who enrolled for the study also advertised it further within their personal networks.

Data that can be collected online. Assuming children and families have time and access to technology, there are still limitations on what type of data can be collected of the digital fabrication and making process, or the design process more generally, if going online is the only option. Further, the quality and quantity of data received from participants can vary widely (Kucirkova et al., 2020). Requesting young children to write, draw, and/or record and share data comes with its own challenges, and usually implies that it is the responsibility of a parent, elder sibling, another family member, or a caregiver to support the child with such tasks. With older child-participants, such as teenagers, even if they have access to computers and phones and are able to share the data themselves, they might not be very inclined to write, draw, or record in the first place. However, researchers can still collect a rich variety of data through online interviews and questionnaires, asking child-participants to reflect on their experiences, performance, and also ask questions.

Regarding online questionnaires, or feedback, various tools can be utilized to make the process engaging and easy. In our study, we created a web-based application, where participants could provide feedback in multiple ways and in their own time, before, during, or after a session at the Fab Lab or at home. The application supported feedback in text, pictures, videos, and audio recordings, and the link was shared with all participants and their parents, so that feedback could be provided anytime. Participants were asked to fill in the feedback at least right after the sessions, just before they packed up to leave the Fab Lab premises. Participants created individual logins during their first application use, and all data was stored to a protected online database. Reminders were sent to the parents or point of contact, to fill in the feedback in case families had to leave early from a session or preferred to give feedback later on. This asynchronous web-friendly data collection method worked well — there was a very short learning curve in familiarizing with the application, which was done together with the researchers in the first session. The flexibility to provide feedback in multiple ways (picture, text, video, audio) and at any time served the digital fabrication and making process well. Further, data collection through web or mobile based applications can be gamified with rewards and badges and even a community Q&A or discussion forum can be created, to engage participants and build motivation for providing feedback throughout the project work, whether participation is online-only or hybrid.

Towards the end of the project, we also utilized videoconferencing. With videoconferencing, researchers can observe social cues and behaviours during online working or interviews, relatively similar to any physical face-to-face process. Most challenges towards videoconferencing are software, hardware, or internet related. The child needs to have access to a device with the needed videoconferencing software installed, and a decent internet connection is also required as a patchy network breaks the communication flow causing a lot of frustration and stress, sometimes making it impossible to continue. If the situation is one-to-many, with either many child-participants for a focus group discussion or group work, or with a family including a parent–child pair, the researcher has to also moderate the power differential and the variation in social acuity of the participants, ensuring each participant is heard and can contribute (Kucirkova et al., 2020). This can be especially difficult in an online scenario where participants can be camera shy and conscious, and talking in a group discussion means that their camera feed could be the main image flashing on everyone's screens. However, previous research shows that shy participants can still prefer virtual modes of communication over face-to-face interactions, e.g., digital interviews (Kucirkova et al., 2020) or written responses (O'Connor & Madge, 2001).

Challenges with online digital fabrication and making tasks. While collecting interview, survey, and questionnaire data is fairly doable online, collecting observation data or documenting the steps of the digital fabrication and making process can be difficult and exhausting for the researcher. For mapping the design process or studying the challenges and their resolutions during hands-on making it can be difficult to position the camera so that it shows both the workspace and the participant's face. It is doable with using multiple devices but that is not necessarily very reasonable to request from the participants. Further, if parents mediate the making activity, as in case of our work, the instructor did not have time to put effort on ensuring that the child is as engaged as the mediating parent. In the parent–child participant pair building a robot during a videoconference with the fab lab instructor, we experienced that the parent was more engaged than the child. Further, they had a Zoom background activated, which meant that the child or parts of the robot kit kept fading in and out of the video feed of the instructor. For design tasks, screen sharing is possible and allows the instructor to either guide step-by-step by sharing their screen or looking at the participants' shared screen. Yet, screen-sharing is not without drawbacks. Often both screens cannot be shared at the same time, which would be possible in physically collated spaces. Sharing one's screen often also hides the video feed of others, making the experience fairly isolating and confusing.

Considering asynchronous sessions, instructors can create and share do-it-yourself tutorials for both digital fabrication and making tasks as well as instructions for how to record the working process for data collection purposes. Child participants and families have more flexibility in this process and can record and share video or audio recordings, document their process, experience, challenges, and thinking aloud. Based on our experience, participants usually are not eager to spend time on providing reflection as a post-activity; therefore, we suggest integrating this process into the activity as one of the steps to get their tasks done. This way a rich data set can be created for analysis. However, there is a huge dependency then on the children and families to share this data, and there could be delays (Kucirkova et al., 2020) or other challenges, for instance with sharing and storing large video files.

Parents collecting data of their children. One way to collect data during remote synchronous or asynchronous digital fabrication and making sessions is together with parents or caregivers, where they step in as proxy-observers (Kucirkova et al., 2020). We have not tried it out yet but have had plans for this, in case the pandemic prevents face-to-face data collection for an extended time period. Surveys, questionnaires, design tasks, short reflections, or storytelling could be used, but very clear instructions for how to collect and record data should be provided, as otherwise there can be an inconsistency in the richness of the data received based on how the adult interprets the questions and response requirement. As Kucirkova et al. (2020) note, some "parents followed [the] request to note down children's verbatim responses", while "other parents described children's behaviour with rich adjectives". Most times, in addition to children's responses or rich descriptions of those, parents mentioned also their own experiences. Thus, both the quality and quantity of data received can vary considerably when there is a dependency on non-researchers to collect data. One way to deal with these challenges is to encourage parents to collect data of their child's maker activities mainly in the form of audio and video, sending them devices such as video or audio recorders (Kucirkova et al., 2020), and also lightly training them as proxy-researchers.

7. Conclusion

In this paper we report and reflect on the challenges caused by the COVID-19 pandemic in the context of children's non-formal technology education, more specifically in fab labs, and identify strategies by which at least some of the challenges can been overcome. We strongly believe that "the show must go on" also during the times of pandemic, and maybe even more so during it, to live our lives as fully as possible. The pandemic alleviates the significance of the skills and competences in design and technology. The situation also challenges us to view our established ways of working with different eyes and opens up a possibility to find new and useful solutions and practices that will serve also in the future, not only in this situation.

We have identified various kinds of digital divides as prohibiting children's engagement in digital fabrication and making activities during the pandemic, in remote or hybrid mode. Those concern both access and ability to use different kinds of means and tools associated with digital fabrication and making. Basic access to computers has not appeared as a problem in our case and 3D design activities can be relatively easily arranged online, while the ability to use the digital fabrication tools might be an issue for children. Access to the machines and ability to safely use them are great problems. The same goes for offering children support and scaffolding their learning during online activities. Children may have difficulties in engaging in education online; they may lack skills and abilities in general, not only relating to digital fabrication and making.

To overcome the challenges, we have experimented with VR and remote-control modes to offer access to the digital fabrication machines. We have also developed training of teachers: we have offered them online tutorials and workshops as well as equipment and support in using them. Moreover, we have plans to offer electronics kits for children to explore. We consider these as valuable developments in offering children non-formal technology education during the times of the pandemic. We consider teachers as highly significant actors here: in order to empower the children as regards design and technology, we need to empower the teachers first. The child–computer interaction (CCI) community has already recognized the importance of empowerment of children as regards design and technology (e.g. Iversen et al., 2017; Kinnula et al., 2017) as well as the importance of teachers in this quest (e.g. Sanchez Milara et al., 2020; Pitkänen et al., 2020). The pandemic has emphasized further their role as enablers of children's digital fabrication and making activities: comprehensive schools have mostly remained open in Finland during the pandemic, while many leisure-time clubs have been closed.

We have also conducted research activities with children and their families during the pandemic. We identify issues as well as positive developments in terms of participant recruitment and research data capture. We emphasize that in the future CCI researchers need to be prepared for more extensive online engagement in research activities with children and families. We consider parents another significant group enabling but potentially also hindering children's engagement in non-formal technology education. We need to figure out ways by which to reach out to the parents and families and enable their remote participation. We maintain that the entire CCI research community should be more engaged in developing our research method repertoire to include online methods for child and family participation to widen our repertoire and to answer the changing circumstances. We see this also as a possibility for CCI research to empower children and their families with technology education and with helping them to find hopefully enjoyable collaborative activities to do together, as a family.

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.

Acknowledgements

This research is connected to the GenZ project, a strategic profiling project in human sciences at the University of Oulu. The project is supported by the Academy of Finland (grant agreements No. 318930, Profi4 and No. 324685, Make-A-Difference) and the University of Oulu. This research was additionally funded by the European Union's Horizon 2020 Research and Innovation programme (grant agreement No. 787476, COMnPLAY SCIENCE).

References

Adnan, M., & Anwar, K. (2020). Online learning amid the COVID-19 pandemic: Students' perspectives. *Journal of Pedagogical Sociology and Psychology*, *2*(1), 45–51.

Andrew, A., Cattan, S., Costa Dias, M., Farquharson, C., Kraftman, L., Krutikova, S., Phimister, A., & Sevilla, A. (2020). Inequalities in children's experiences of home learning during the COVID-19 lockdown in England. *Fiscal Studies*, *41*(3), 653–683.

Antle, A. N., & Frauenberger, C. (2020). Child-computer interaction in times of a pandemic. *International Journal of Child-Computer Interaction*, *26*, Article 100201.

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. *FabLabs: Of Machines, Makers and Inventors*, *4*(1), 1–21.

Buehler, E., Easley, W., McDonald, S., Comrie, N., & Hurst, A. (2015). Inclusion and education: 3D printing for integrated classrooms. In *Proceedings of the 17th international ACM SIGACCESS conference on computers and accessibility* (pp. 281–290). Association for Computing Machinery, Inc., https://doi.org/10.1145/2700648.2809844.

Chilana, P. K., Hudson, N., Bhaduri, S., Shashikumar, P., & Kane, S. (2018). Supporting remote real-time expert help: Opportunities and challenges for novice 3d modelers. In *Proceedings of IEEE symposium on visual languages and human-centric computing, VL/HCC* (pp. 157–166). IEEE Computer Society, https://doi.org/10.1109/VLHCC.2018.8506568.

Constantin, A., Alexandru, C., Korte, J., Wilson, C., Fails, J. A., Sim, G., Read, J., & Eriksson, E. (2021). Distributing participation in design: Addressing challenges of a global pandemic. *International Journal of Child-Computer Interaction*, *28*, Article 100255.

Dong, C., Cao, S., & Li, H. (2020). Young children's online learning during COVID-19 pandemic: Chinese parents' beliefs and attitudes. *Children and Youth Services Review*, *118*, Article 105440.

Engzell, Per, Frey, Arun, & Verhagen, Mark D. (2020). *Learning inequality during the Covid-19 pandemic, SocArXiv Ve4z7*. Center for Open Science, https://ideas.repec.org/p/osf/socarx/ve4z7.html.

Flack, C. B., Walker, L., Bickerstaff, A., & Margetts, C. (2020). *Socioeconomic disparities in Australian schooling during the COVID-19 pandemic*. Melbourne, Australia: Pivot Professional Learning.

Goagoses, N., Winschiers-Theophilus, H., & Chamunorwa, M. B. (2020). The (potential) role of technology for Young children's social-emotional learning: During and beyond the COVID-19 pandemic. *Digital Government: Research and Practice*, *2*(1), 1–6.

Grimme, S., Bardzell, J., & Bardzell, S. (2014). 'We've conquered dark': Shedding light on empowerment in critical making. In *Proceedings of the 8th nordic conference on human-computer interaction* (pp. 431–440). https://doi.org/10.1145/2639189.2641204.

Hatch, M. (2014). *The maker movement manifesto*. New York: McGraw-Hill Education.

Hudson, N., Alcock, C., & Chilana, P. K. (2016). Understanding newcomers to 3D printing: Motivations, workflows, and barriers of casual makers. In *Proceedings of the ACM CHI conference on human factors in computing systems* (pp. 384–396). Association for Computing Machinery, https://doi.org/10.1145/2858036.2858266.

Hudson, N., Lafreniere, B., Chilana, P. K., & Grossman, T. (2018). Investigating how online help and learning resources support children's use of 3D design software. In *Proceedings of the ACM CHI conference on human factors in computing systems*. Association for Computing Machinery, https://doi.org/10.1145/3173574.3173831.

Iivari, N., & Kinnula, M. (2016) 'It has to be useful for the pupils, of course' – Teachers as intermediaries in design sessions with children. In: U.L. Snis (ed.) In *Nordic Contributions in IS Research, 7th Scandinavian Conference on Information Systems*, SCIS 2016 and IFIP8.6 2016. Springer, pp. 16–28.

Iivari, N., & Kinnula, M. (2018). Empowering children through design and making: towards protagonist role adoption. In *Proceedings of the 15th participatory design conference* (pp. 1–12).

Iivari, N., Kinnula, M., Kuure, L., & Molin-Juustila, T. (2014). Video diary as a means for data gathering with children - encountering identities in the making. *International Journal of Human-Computer Studies*, *72*(5), 507–521.

Iivari, N., Sharma, S., & Ventä-Olkkonen, L. (2020). Digital transformation of everyday life–How COVID-19 pandemic transformed the basic education of the young generation and why information management research should care? *International Journal of Information Management*, *55*, Article 102183.

Iversen, O. S., Smith, R. C., & Dindler, C. (2017). Child as protagonist: Expanding the role of children in participatory design. In *Proceedings of the international conference on interaction design and children*, ACM, pp. 27–37.

Jayathirtha, G., Fields, D., Kafai, Y. B., & Chipps, J. (2020). Supporting making online: the role of artifact, teacher and peer interactions in crafting electronic textiles. *Information and Learning Science*, *121*(5/6), 381–390, https://doi.org/10.1108/ILS-04-2020-0111.

Kinnula, M., & Iivari, N. (2021). Manifesto for children's genuine participation in digital technology design and making – insights gained through working with children. *International Journal of Child-Computer Interaction*, *28*, Article 100244.

Kinnula, M., Iivari, N., Molin-Juustila, T., Keskitalo, E., Leinonen, T., Mansikkamäki, E., Käkelä, T., & Similä, M. (2017). Cooperation, combat, or competence building – What do we mean when we are 'empowering children'? In *Proceedings of the International Conference on Information Systems (ICIS)*, AIS.

Kinnula, M., Iivari, N., Sanchez Milara, I., & Ylitalo, J. (2020). Guidelines for empowering children to make and shape digital technology – case fab lab oulu. In Michail Giannakos (Ed.), *Lecture notes in educational technology (LNET), Non-formal and informal science learning in the 21st century – current trends, research and practice*. Springer.

Kucirkova, N., Evertsen-Stanghelle, C., Studsrød, I., Bruheim Jensen, I., & Størksen, I. (2020). Lessons for child–computer interaction studies following the research challenges during the Covid-19 pandemic. *International Journal of Child-Computer Interaction*, *26*, Article 100203.

Kuure, L., Halkola, E., Iivari, N., Kinnula, M., & Molin-Juustila, T. (2010). Children Imitate! Appreciating recycling in participatory design with children. In *Proceedings of the 11th biennial participatory design conference* (pp. 131–140). ACM.

Lafreniere, B., & Grossman, T. (2018). Blocks-to-CAD: A cross-application bridge from minecraft to 3D modeling. In *Proceedings of the 31st annual ACM symposium on user interface software and technology* (pp. 637–648). Association for Computing Machinery, Inc., https://doi.org/10.1145/3242587.3242602.

Lee, V. R., Lewis, W., Searle, K. A., Recker, M., Hansen, J., & Phillips, A. L. (2017). Supporting interactive youth maker programs in public and school libraries: Design hypotheses and first implementations. In *Proceedings of the international conference on interaction design and children* (pp. 310–315). Association for Computing Machinery, Inc., https://doi.org/10.1145/3078072.3079741.

Norouzi, B., Kinnula, M., & Iivari, N. (2021). Making sense of 3D Modelling and 3D printing activities of young people - A nexus analytic inquiry, In *Proceedings of the ACM CHI conference on human factors in computing systems*, Association for Computing Machinery.

O'Connor, Henrietta, & Madge, Clare (2001). Cyber-mothers: Online synchronous interviewing using conferencing software. *Sociological Research Online*, *5*(4), 102–117.

Okerlund, J., & Wilson, D. (2019). DIY assistive technology for others: Considering social impacts and opportunities to leverage HCI techniques. In *Proceedings of the creativity in fabrication and education conference* (pp. 152–155). Association for Computing Machinery, https://doi.org/10.1145/3311890.3311914.

Pitkänen, K., Iwata, M., & Laru, J. (2020). Exploring technology-oriented fab lab facilitators' role as educators in K-12 education: Focus on scaffolding novice students' learning in digital fabrication activities. *International Journal of Child-Computer Interaction*, *26*, Article 100207.

Rajanen, D., & Rajanen, M. (2020). Safety culture in digital fabrication: Perceptions, model and co-creation approach. *Journal of Higher Education Theory and Practice*, *20*, 14.

Rieman, John (1996). A field study of exploratory learning strategies. *ACM Transactions on Computer-Human Interaction*, *3*(3), 189–218, https://doi.org/10.1145/234526.234527.

Sanchez Milara, I., Pitkänen, K., Laru, J., Iwata, M., Orduña, M. C., & Riekki, J. (2020). STEAM in oulu: Scaffolding the development of a community of practice for local educators around STEAM and digital fabrication. *International Journal of Child-Computer Interaction*, *26*, Article 100197.

Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review*, *84*(4), 505–531.

Shewbridge, R., Hurst, A., & Kane, S. K. (2014). Everyday making: Identifying future uses for 3D printing in the home. In *Proceedings of the 2014 conference on designing interactive systems* (pp. 815–824). Association for Computing Machinery., https://doi.org/10.1145/2598510.2598544.

Silver, J. (2009). Awakening to maker methodology: The metamorphosis of a curious caterpillar. In *Proceedings of the 8th International conference on interaction design and children* (pp. 242–245). ACM Press, https://doi.org/10.1145/1551788.1551841.

Stacey, M. (2014). The FAB LAB network: A global platform for digital invention, education and entrepreneurship. *Innovations: Technology, Governance, Globalization*, *9*(1–2), 221–238.

Tisza, G., Papavlasopoulou, S., Christidou, D., Iivari, N., Kinnula, M., & Voulgari, I. (2020). Patterns in informal and non-formal science learning activities for children–A Europe-wide survey study. *International Journal of Child-Computer Interaction*, *25*, Article 100184.

Vossoughi, S., & Bevan, B. (2014). Making and tinkering: A review of the literature | informalscience.org. In *National research council committee on out of school time STEM, 2014*. https://www.informalscience.org/making-and-tinkering-review-literature.