

From Digital Fabrication to Meaningful Creations: Pedagogical Perspectives

Calkin Suero Montero¹, Christian Voigt², Kati Mäkitalo³

¹ School of Computing, University of Eastern Finland, Finland

² Zentrum für Soziale Innovation, Austria

³ Faculty of Education, University of Oulu, Finland

{calkins@uef.fi | voigt@zsi.at | kati.makitalo@oulu.fi}

Abstract. Digital fabrication consists in a range of techniques used to create products from digital designs. For the development of the digital citizen, digital literacy is a fundamental skill. However, the current education system widely used is heavily reliant on traditional education methods and activities or use technology to promote old ways instead of innovative thinking. In this work, we look at pedagogical approaches that facilitate the intake of technology to be used in educational contexts. First, we present our inquiry and design thinking based approach that encompasses five stages: ideation, planning, creation, programming and sharing to imbue digital fabrication with meaningful creations. The paper continues to present students' work and provides a summary feedback from teachers. We conclude by arguing that teaching approaches and learning stages are good to structure learning through digital fabrication ex-ante, but that there is a need to also support the experiential dimension on the teachers' side to make it work by acquiring a 'coach's mindset', following students' ideas.

Keywords: technology innovation, craft- and project-based pedagogy, inquiry-based learning, design thinking

1 Introduction

Digital fabrication allows to (re)create, tinker and develop artefacts using digital technologies such as 3D design and printing, laser cutting. In education, digital fabrication is also tied to the rise of the *maker movement*¹ and the spread of the *FabLab movement*², both based on Papert (1980) constructionist agenda in order “to empower, to educate and to create ‘almost everything’” (Nunez, 2010; Gershenfeld, 2012). The empowerment that digital fabrication facilitates has been brought to schoolchildren (for example, see the work of Blickstein, 2013, and Blickstein & Krannich, 2013). It has been argued that such empowerment is not only useful to develop competences in science, technology, engineering and math but also to understand better the current digital

¹ Maker culture is technology-based extension of the DIY culture encouraging novel technology applications or creation (see for instance Wikipedia, 2018)

² A Fablab (fabrication lab) is low cost lab equipped with digital fabrication technologies (see Blickstein, 2013).

society in which we live in and the self (see Schelhowe, 2012 as cited by Smith et al. 2015) as a digital citizen.

Moreover, digital fabrication in education has also been praised for fostering the development of 21st century digital citizen skills including creativity, collaborative work and problem solving (Alimisis, 2013). This shows the enormous potential that digital fabrication presents for enhancing educational activities. One problem that seems to appear with the inclusion of digital fabrication in education is, however, that school children and teachers alike may fall prey to only make predefined and risk-free and oversimplified exercises, where construction becomes a mere “push-button” activity (Eisenberg, 2013). This type of activities and exercises might in the end only diminish the learning potential that digital fabrication technology can actually afford. Blikstein (2013) points out this “keychain syndrome” where students and teachers are only involved in producing simple aesthetic artefacts such as a keychain. Our work proposes to go beyond the creation of simple aesthetic objects to reap the potential that digital fabrication and making can bring to education: empowerment to create almost anything while applying the concepts that fuel inquiry-based learning.

Therefore, in this paper we look at how digital fabrication is deployed through a solid inquiry based, craft- and project-based pedagogical approach. The idea is to bring forward the importance of a pedagogical framework for teachers and educators when using digital fabrication in the classroom. We argue that the combination of a pedagogical approach with the endless learning opportunities afforded by the use of digital fabrication in the classroom will facilitate the inclusion of innovative technologies in education. Working on Papert’s constructivists ideas, our aim is to facilitate the 21st century digital citizen process to be empowered, educated, and able to create almost everything.

2 Related Work

Research shows that digital fabrication technologies afford many opportunities for empowerment (Blikstein, 2013), development of 21st century skills (Alimisis, 2013) and even development of the self-perception as a digital citizen (Smith et al. 2015). However, in education the potential to deploy these benefits for learning by creating concrete artefacts using digital fabrication seems to be lacking. Several reasons for this have been identified as it has happened when information and communication technologies are more or less successfully implemented in the classroom. For instance, challenges of technology availability, teachers’ technological, pedagogical and content knowledge confidence of using the technologies, teachers’ mindset, attitude as well as training, to name a few (see Häkkinen et al., 2016; Mäkitalo-Siegl et al., 2011; Valtonen et al., 2018; Valtonen et al., 2012). A big barrier appears when teachers have little knowledge about how to utilise a technology in a meaningful way in their educational activities, particularly when teachers have to change the pedagogy used in the classroom in order to utilise the technology (Mäkitalo-Siegl et al., 2011).

There have been several attempts to meaningfully introduce digital fabrication in educational contexts, nevertheless. For example, Blikstein & Krannich (2013) report on attempts to introduce digital fabrication and making in formal and informal education arena from the perspectives of practical experiences as well as research approaches. In addition, Katterfeldt et al. (2015) highlight their results of deploying constructivist learning environments for digital fabrication using programmable construction kits. They report on the use of digital fabrication technologies to foster deep and sustainable learning (*Bildung*). In a special issue on digital fabrication in education for the International Journal of Child-Computer Interaction, Iversen et al. (2016) put forward contributions on bringing digital fabrication environments to education from several perspectives. These perspectives include the need of new curricula, social protocols, facilitation and tools demonstrating the scientific community interest to establish and reap the benefits of digital fabrication in the educational terrain. Of particular interest to our work, Smith et al. 2015 and Smith et al. 2016, propose a design thinking approach to digital fabrication, stressing the creative process from ideation to prototype. Smith et al. (2016) work highlights three barriers of introducing digital fabrication in education from the perspective of the teacher through the design thinking approach lens: the complexity of the design process, the management of technologies and materials and the issue of balancing different teacher's roles.

Yet, the challenges outlined in those contributions are still to be fully met. The question of how do we reach the demands of 21st century work and digital society life within the educational arena to provide children with the necessary skills for *Bildung* and for becoming capable digital citizen is still a wide research arena. Taking a pedagogical perspective stand, we propose a five-stage craft- and project-based approach to digital fabrication that includes elements of design thinking and inquiry-based learning to facilitate the inclusion of digital fabrication in formal and informal educational settings.

3 The Pedagogical Model

Our approach combines elements of design principles and inquiry-based learning to form methodological steps for the inclusion and utilization of technology for the creation of computer supporting artefacts. The aim is to produce a craft- and project-based pedagogy. This pedagogy is derived from the inquiry-based learning methods, and expanded to include both the knowledge and the specific end-product which needs to be created through design thinking.

The inquiry-based learning starts by posing questions, problems or scenarios and a coach or facilitator of the learning experience usually supervises the process. Students then identify and research issues and questions to develop their knowledge or solutions. The process is intrinsically argumentative, where the students create questions, obtain supporting evidence to answer the questions, explain the evidence collected, connect the explanation to the knowledge obtained from the investigative process and finally

create an argument and justification for the explanation. In order to enhance this process of inquiry, we draw from the design thinking method as hands-on counterpart.

We have seen design thinking used for digital fabrication deployment in education (Smith et al., 2015, Smith et al., 2016). Design thinking is a method for practical, creative solutions of problems with the intent of improve future results. Design thinking is a form of solution-based or solution-focused thinking that has been suggested for use in schools in a variety of curricular ways, as well as for redesigning student spaces and school systems (Bekker et al. 2015). Design thinking is employed to promote creative thinking, teamwork, and student responsibility for learning. Since the students work together in groups, design thinking in education also encourages collaborative learning. Design thinking involves understanding with the learners exploring the topic; observing the environment; generating alternative point of view to enhance understanding; ideating solutions with an emphasis on creativity and enjoying the process; prototyping to investigate the ideas generated during ideation; and testing the ideas iteratively.

Our project deploys *a craft- and project-based* methodology, a combination of the inquiry-based learning with design thinking through the use of DIY and 3D printing technologies in order to enhance the pedagogical outcomes of the individually applied inquiry-based and design thinking methods. The craft- and project-based methodology involves the following processes (see Figure 1):

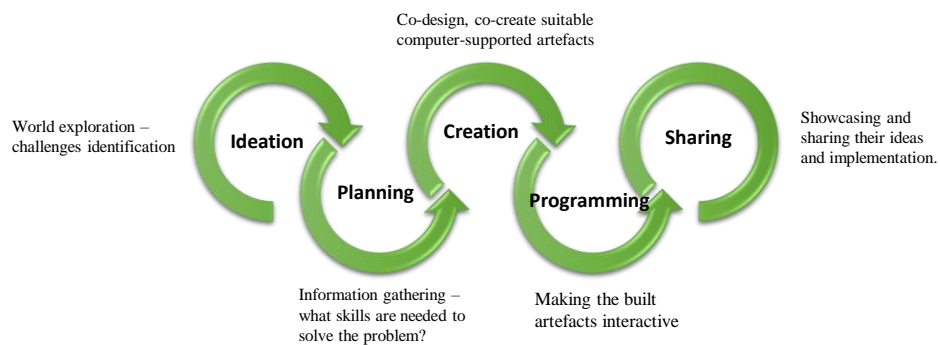


Figure 1. Five-stage pedagogical approach of our project

Stage 1: Ideation through world exploration – in order to find out what kind of challenge they or someone else is facing in their daily life. The students could explore the world physical (e.g., taking pictures, exploring situations outside the classroom, etc.) or virtually (e.g., through online support community discussion) and then decide what their challenge will be. Alternatively, to facilitate the integration with school curricula, the teacher coach can pose an open problem taken from their subject matter for the students to come up with solutions to it. The teacher coach guides this process.

Stage 2: Planning. Once the challenge has been defined, the students collect information to make a project plan – they can get feedback from the teacher coach on their project plan and on the roles for group members. This they can also perform in parallel with ideation and creation stages

Stage 3: Creation. In this stage, the students embark on the co-design and co-creation of their computer-supported artefact solutions through the application of digital fabrication technologies. Visualisation and simulation of the designs are also important parts of this stage.

Stage 4: Programming. Once the computer-supported artefacts are built, the students define suitable scripts (high-level programming language) for the functioning of their artefacts. Software debugging and integrated SW/HW simulation are two other parts of this stage. We use Snap4Arduino programming environment.

Stage 5: Sharing. In order to enhance motivation, the students will be encouraged to share and showcase their projects and implementation ideas. This will be done through the open (online) community or through peer sharing in the classroom. In return, the students have the opportunity to receive feedback from open community worldwide.

4 Children's Creations

In our work, we aim at using craft- and project-based activities as part of the school curricula in formal settings as well as part of informal education activities (e.g. after-school clubs, Fablabs and maker spaces, etc.). This is so in order to foster creativity and the integration of arts with science, technology, engineering and math subjects within a sophisticated technical environment and using crafts materials (e.g., wood, pipe cleaners, construction paper, cotton balls, glitter and so forth).

We recruited teacher volunteers from local schools and gave them 12 hours of training on the pedagogical concepts of constructivism, constructionism, DIY philosophy, maker movement, design thinking and inquiry-based learning, which form the basis for our craft- and project-based methodology. The concepts of the transformation of the teacher's role to that of a coach or facilitator of the learning experience was also discussed during the training. Furthermore, they were introduced to digital fabrication technologies (e.g., 3D modelling with TinkerCAD, 3D printing, Arduino boards, resistors, light emitting diodes and other electronic components, and so forth) and to basic programming with Snap4Arduino programming environment.

We carry out two curricular activities through our craft- and project-based pedagogical approach to digital fabrication at a junior high school in eastern Finland. The activities formed part of the pilots of our project. Three classes of school students participated in the activities. One class was given the task to represent and model the concept of photosynthesis, as part of their biology class. The other two classes were tasked with the representation of the concept of security in society, as part of their social studies. Students were 14 years old in 8th grade (photosynthesis) and 15 years old in 9th grade (security). The biology class had 18 students (14 girls - 4 boys), and in social studies one class had 13 students (all girls) and the other 15 (3 girls - 12 boys). They divided themselves into groups of 4 or 5 students each. They had no previous use of digital fabrication technologies in the classroom. The data was collected through photos, videos and recordings of the students' working sessions, semi-structured interviews with teachers and students about the activities, as well as the researchers' notes (Ketterfeldt et al. 2015). All ethical procedures for data collection were followed and teachers and students alike consented for their data to be collected and used for research purposes and for improving the learning environment and activities. Due to space constraints, we present here pictures illustrating the five-stage pedagogical approach to digital fabrication for modelling the photosynthesis process.

Each class was introduced to the basic concepts of programming with blocks in Snap4Arduino environment as well as 3D modelling and printing in an introductory hands-on lesson.

Photosynthesis activity

- *Ideation and planning.* Students were briefed by their teachers on the background concepts of photosynthesis and were then encouraged. Figure 2 shows a the sketches of one group's ideation and planning



Figure 2. A group ideation and planning sketching of their their photosynthesis model

- *Creation and programming.* During the creation or *making* of their models, students employed a variety of materials including crafting materials (e.g., hot glue, ropes, etc.), recycled materials (e.g., cardboard and pet bottles) as well as 3D printed elements. The students also familiarised themselves with basic *programming* blocks, in Snap4Arduino programming environment enough for them to expand their knowledge while tinkering with their creations in order to make the artefacts interactive. For instance, one group representation of

photosynthesis used sensors to indicate when the water levels of the plant were low (i.e., below a threshold) and flashed a visual alarm (using LEDs) to indicate that photosynthesis could not occur without water. Figure 3 shows student groups in the process of *making* their models.

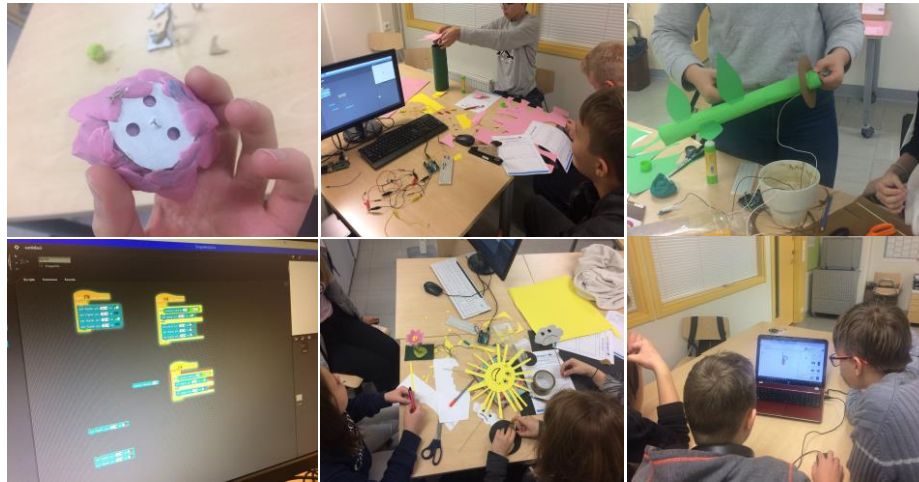


Figure 3. Student groups working on the physical creation of their model while making their artefacts interactive through programming

- *Sharing.* After their representation model was created and it was interactive in the way they had planned, the students were encouraged to present their work to their peers. The sharing of their ideas involved describing what they understood photosynthesis was and how they had chosen to represent it. Figure 4 shows student groups during their demonstrations.



Figure 4. Groups showcasing their model representation to peers and to teacher coach

5 Teacher's Role

In our work, we consider the transformation of the teacher role to that of a coach or facilitator of the learning experience. To some extent this agrees with the notion of teachers as 'orchestrators' of the learning experience (Dillenbourg & Jermann, 2010). We believe, however, that this orchestration needs to be achieved in student-centred learning practices, where the student is the protagonist of the learning experience. The integration of digital fabrication in education brings with it new perspectives for students to learn. As such, personalised learning provides students the opportunity to learn in ways that is preferable for themselves by setting their learning objectives for their own learning. Each student may have different objectives, but the teacher should apply differentiated strategies to promote the personal potentiality. Teacher's role is acting more as a coach. For students this means that self-regulation is a fundamental skill and not only the cognitive, but all dimensions of learning will be in focus (emotional, social, life experience etc.). (See Fullan, 2009; Patrick, 1997).

Personalised learning sets challenges for a teacher:

- One of the challenges is how to support deeper learning for each learner, adapted to each individual's knowledge level and expectations.
- A second challenge is to connect learners' world and day-to-day experiences with in-class learning (Hargreaves & Shirley, 2009).

Digital fabrication could tackle such challenges, albeit perhaps creating issues of self-efficacy perception from the teacher's perspective (as reported by Smith et al., 2016, for instance). However, these challenges are not trivial for teachers who expect themselves to be knowledgeable all the time. The sheer number of possible scenarios and questions makes it unlikely that teachers know it all. In such situations, being a coach can mean to help students finding the answer or parts thereof by directing them to external resources that could contain the required information. On the teachers' side, the skill of searching effectively is best acquired by being tinkerers themselves, realizing their own projects and developing a sense for when to 'move the goalpost' and when to stick to it because one is confident that there must be a solution. This level of self-efficacy can only be acquired through experience. Our eCraft2learn project supports teachers in gaining this experience through offering training and space to explore the benefits of digital fabrication technologies alongside the pedagogical model described before.

The pedagogical model was implemented and tested during two pilots that deployed curricular tasks like the ones shown in previous sections, as well as activities in after-school clubs. From the pilots we could obtain feedback from nine teachers who participated. Comments and feedback were collected through semi-structured interviews as well as researchers notes during the training sessions, documented by observers and moderators of the sessions. Following a few excerpts of the teachers' views:

- Teachers agreed that *learning-by-making* supports learning. When students notice that something does not work or a different solution could have been better, they will analyse the problem, search for information and the next time they manage to do things more smoothly.
- Teachers admitted that they have quite limited knowledge and a narrow or stereotypical view of technology. One teacher was amazed how many new possibilities for the creation of technology he discovered during the project. This related primarily to the fact that sensors provided endless opportunities to children who wanted to modify the behaviour of a ‘robot’, that could take the shape of a flower.
- Teachers also found that some fundamental dependencies had to be acknowledged, such as knowing basic programming constructs and the use of variables. Otherwise introducing those concepts would be quite time consuming. This does not mean that all programming needs to be taught prior to a making project, and an overview session was considered to be sufficient.
- Teachers also noticed how challenging the ideation phase could be, since they had limited background information about the workings of different sensors and other electronic components. This highlights the need to match the novelty of a topic with the appropriate learning strategy. For example, it is known that for novice learners worked-examples can be very effective (Renkl, 2005). Over time, with more contextual knowledge available, the need for examples decreases and problem-based approaches become more effective. From the teachers’ point of view, there had to be a balance between student- and teacher-led learning. When introducing difficult content, a teacher cannot shift all the responsibility onto students. It is necessary to use a degree of scaffolding depending on students’ current level of understanding.
- Finally, teachers noticed the importance of time-management. Students should set goals consciously and be reminded to monitor their own work in relation to the goals. Too tight schedules can excessively limit the work and learning about effective time-management practices.

5 Concluding Reflections

Here we have presented our approach to bring digital fabrication to educational context. Our approach puts forward a craft- and project-based pedagogy in order to facilitate the intake of digital technologies into formal school grounds. We presented examples of the students’ steps and works through the five-stage pedagogy from the ideation, planning, creation and programming to the sharing of their artefacts. We could observe the integration of digital fabrication in school curriculum activities through the application of our pedagogical approach. Teachers’ role as a coach that orchestrate the learning experience during the process is emphasised in this approach. We highlighted the importance of working under a pedagogical umbrella that teachers can assimilate and understand in order to facilitate the inclusion of digital fabrication in the classroom.

Acknowledgment

The work presented here was carried out under the H2020 eCraft2Learn Project. This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme, grant agreement n° 731345

References

- Alimisis, D. (2013). Educational robotics: Open questions and new challenges. *Themes in Science and Technology Education*, 6(1), 63-71.
- Bekker, T., Bakker, S., Douma, I., Van Der Poel, J., & Scheltenaar, K. (2015). Teaching children digital literacy through design-based learning with digital toolkits in schools. *International Journal of Child-Computer Interaction*, 5, 29-38.
- Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. *FabLabs: Of machines, makers and inventors*, 4, 1-21.
- Blikstein, P., & Krannich, D. (2013, June). The makers' movement and FabLabs in education: experiences, technologies, and research. In *Proceedings of the 12th international conference on interaction design and children* (pp. 613-616). ACM.
- Dillenbourg, P., & Jermann, P. (2010). Technology for classroom orchestration. In *New science of learning* (pp. 525-552). Springer, New York, NY.
- Eisenberg, M. (2013). 3D printing for children: What to build next? *International Journal of Child-Computer Interaction*, 1(1), 7-13.
- Fullan, M. (2009). Personalized learning. Online at https://michaelfullan.ca/wp-content/uploads/2016/06/Untitled_Document_16.pdf
- Gershenfeld, N. (2012). How to make almost anything: The digital fabrication revolution. *Foreign Aff.*, 91, 43.
- Hargreaves, A. P., & Shirley, D. L. (Eds.). (2009). *The fourth way: The inspiring future for educational change*. Corwin Press.
- Häkkinen, P., Järvelä, S., Mäkitalo-Siegl, K., Ahonen, A. K., Näykki, P., & Valtonen, T. (2016). Preparing teacher students for twenty-first-century learning practices: a framework for enhancing collaborative problem-solving and strategic learning skills. *Teachers and Teaching: Theory and Practice*, 23(1), 25-41.

Iversen, O.S., Smith, R.C., Blikstein, P., Katterfeldt, E.-S., Read, J.C. (2016) Digital fabrication in education: Expanding the research towards design and reflective practices, *International Journal of Child-Computer Interaction*
<http://dx.doi.org/10.1016/j.ijcci.2016.01.001>

Katterfeldt, E. S., Dittert, N., & Schelhowe, H. (2015). Designing digital fabrication learning environments for Bildung: Implications from ten years of physical computing workshops. *International Journal of Child-Computer Interaction*, 5, 3-10.

Nunez, J. G. (2010). *Prefab the FabLab: rethinking the habitability of a fabrication lab by including fixture-based components* (Doctoral dissertation, Massachusetts Institute of Technology).

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc.

Patrick, H. (1997). Social self-regulation: Exploring the relations between children's social relationships, academic self-regulation, and school performance. *Educational Psychologist*, 32(4), 209-220.

Renkl, A. (2005). The worked-out examples principle in multimedia learning. In Mayer, R.E. (Ed.), *The Cambridge Handbook of Multimedia Learning*. Cambridge: Cambridge University Press

Schelhowe, H. (2012). Interaktionsdesign für reflexive Erfahrung. Be-greifbare Interaktionen (pp. 253–272). Bielefeld, Germany: Transcript Verlag
Smith, R. C., Iversen, O. S., & Hjorth, M. (2015). Design thinking for digital fabrication in education. *International Journal of Child-Computer Interaction*, 5, 20-28.

Smith, R. C., Iversen, O. S., & Hjorth, M. (2015). Design thinking for digital fabrication in education. *International Journal of Child-Computer Interaction*, 5, 20-28.

Smith, R. C., Iversen, O. S., & Veerasawmy, R. (2016). Impediments to Digital Fabrication in Education: A Study of Teachers' Role in Digital Fabrication. *International Journal of Digital Literacy and Digital Competence*, 7(1), 33-49.

Mäkitalo-Siegl, K., Kohnle, C., & Fischer, F. (2011). Computer-supported collaborative inquiry learning and classroom scripts: Effects on help-seeking processes and learning outcomes. *Learning and Instruction*, 21(2), 257-266.

Valtonen, T., Kukkonen, J., Kontkanen, S., Mäkitalo-Siegl, K., & Sointu, E. (2018). Differences in pre-service teachers' knowledge and readiness to use ICT in education. *Journal of Computer Assisted Learning*, 1-9. DOI: 10.1111/jcal.12225

Valtonen, T., Mäkitalo-Siegl, K., Kontkanen, S., Pöntinen, S., & Vartiainen, H. (2012). Facing challenges with new teachers' use of ICT in teaching and learning. *IEEE Learning Technology Newsletter*, 14(4), 46-49.

Wikipedia contributors. (2018, July 17). Maker culture. In *Wikipedia, The Free Encyclopedia*. Retrieved, July 31, 2018, from https://en.wikipedia.org/w/index.php?title=Maker_culture&oldid=850779485