The Fifth International Conference on Design Creativity (ICDC2018)
Bath, UK, January 31st – February 2nd 2018

IDEA GENERATION CHALLENGES IN DIGITAL FABRICATION

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Abstract: Digital fabrication is an educational and activity paradigm in which multidisciplinary knowledge, hands-on skills, and teamwork among the makers are essential for success. One of the most significant outcomes of digital fabrication is the product built using particular processes. It has been clearly demonstrated that this paradigm promotes creativity. However, in the setting of digital fabrication education, the creativity of projects varies and sometimes creativity is difficult to nurture and the creativity of the students' projects have a broad variation. In this paper, we analyse creative idea generation in the case of a digital fabrication course. The creativity of the generated ideas is analysed qualitatively in terms of the generated ideas, their characteristics, their goals, and the reflections of students on the course, as well as in the context of the exemplary solution provided at the beginning of the course. Challenges for promoting the creativity in these settings are explored, along with their possible solutions.

Keywords: *digital fabrication, FabLab, making, idea generation, concept generation, creativity, gadgets, Arduino*

1. Introduction

Digital fabrication is an educational and activity paradigm in which multidisciplinary knowledge and different skills intersect for the fast realization of ideas. The digital fabrication in Digital Fabrication Laboratories (FabLabs) incorporates 2D design, 3D design, use of tools and machines, prototyping with electronics, and programming into the process of making physical prototype (Sánchez Milara et al., 2017). FabLabs also serves as a space where creative production takes place from the perspectives of many disciplines as users blend digital and physical technologies to explore ideas, learn skills, and create (Sheridan et al., 2014).
The characteristics of the FabLabs differ from the typical conditions of engineering design shop classes. (Blikstein, 2013). In the FabLabs, the rigorous, disciplined, and scripted experiences of a science lab are substituted with experiential education and constructionism. These fabrication laboratories merge computation, tinkering, and engineering. The FabLabs provides a 'safe space' for projects, which in turn enables students to face the new and intense experience of failure and understand how to manage it (Blikstein, 2013). The overall multidisciplinary aspect (Martin, 2015) and multifaceted experience converge into the digital fabrication space.

1.1. Idea generation in digital fabrication

The multidisciplinary aspect of creating in FabLabs is one particular challenge for novices in digital fabrication (Sánchez Milara et al., 2017). Furthermore, encouraging imagination without creating too many restrictions is a major challenge for fabrication and prototyping courses (Carrington et al., 2015). In digital fabrication, students play a more active role in learning and thinking (Blikstein, 2013). This is not to underestimate the role of the teacher in this learning process (Smith et al., 2016).

This paradigm creates not only opportunities related to creativity but also various challenges to be overcome, like building confidence (Analytis et al., 2015). The open-ended character of digital fabrication also creates a challenge for evaluating creativity (Georgiev et al., 2016) and consequently to take measures to promote creativity where it faces different obstacles.

1.2. Creativity in digital fabrication

Various methods used to evaluate the creativity of student designs in engineering design courses are reported in previous research (Oman et al., 2013). However, the challenge of evaluating and understanding creativity in digital fabrication is even greater compared to the cases when student designs are produced in answer to a particular design brief (e.g. realizing a particular function). Students of digital fabrication are often given an open-ended design brief, leaving the potential for unrestricted idea generation and materialization.

One approach is to demonstrate what is possible in regard to prototyping and experimenting by providing digital fabrication students with an exemplary solution (Georgiev et al., 2016). However, a common issue of such an exemplary solution is that it may influence the creativity of the generated ideas—particularly the degree of originality of such ideas—which often leads to design fixation (Linsey et al., 2010).

Our particular interest in the context of digital fabrication is the creative process and, to a lesser extent, the creative product rather than the creative person or press (Rhodes, 1961). Creativity is a complex and multi-faceted concept; here, we explore creativity as a process by which innovation takes place in order to produce design outputs, some of which will be 'creative' (Howard et al., 2008). The aspects that affect the creative process in the context of digital fabrication form our focus, particularly because of the multidisciplinary complexity of digital fabrication.

In this study, we first briefly review previous works on idea generation in digital fabrication in the next section. We then introduce the case study of a university course in digital fabrication in Section 3. The course comprises designing and building interactive physical prototypes by student teams in FabLabs. The students' documentation of the designing and building processes serves as the primary source of data.

This study is part of a research on creativity and idea generation in digital fabrication and it is in its initial phase. This particular study concerns the specificity of digital fabrication as a design activity paradigm as a whole and as a learning paradigm—focusing on an educational case in particular.

The goals of this study are to (1) identify the common obstacles for the creativity of student teams in the context of digital fabrication of prototypes by combining mechanical, electrical, and software components and (2) identify the challenges for promoting the creativity of the resulting prototypes in such settings. The research question is: What are the possible directions for solving challenges regarding to creativity in the context of digital fabrication?

2. Case study

To answer these questions, we analyse the results of a nine-week course in digital fabrication in university settings (Principles of Digital Fabrication course, 2017). The course is accessible by students from all faculties of the university. This course involves creating interactive physical prototypes that combine mechanical, electrical, and software components. It teaches students to integrate these components with sensors and actuators in order to create a physical gadget that interacts with the world around it. The course is structure in two weeks of theoretical lectures and 7 weeks of project work. During the first two weeks, students took 6 lectures on Introduction to Fab Lab, Design of physical things, Electronics, Embedded programming basics, 3D design and printing, and 2D design. Project work did not have a planned schedule, and students could work to their own pace. The course is completed with a final presentation of the team project (the prototype of the interactive gadget and the documentation adherent to the designing and making of the gadget). The documentation typically consists of three parts—an introductory part focused on the description of the idea generation process and idea that the team arrived at, a weekly diary, and a summary of results and reflections. The gadget must comply with the following requirements: (1) it must consist mostly of parts (mechanic and electronic) designed and manufactured in FabLabs; (2) it needs to have moving parts that are controllable by software; (3) it must have at least one sensor, and the software needs to react to its readings somehow.

The students are provided with an exemplary project (alarm clock robot that runs away when the alarm starts to ring and the user touches the device) and a list of available electronic components (list includes considerably more components than those needed for the exemplary project; extra components were delivered on request). The exemplary solution is presented without much emphasis in order to minimize its effect (Linsey, 2010).

Thirty students started the course but six out of 10 teams (typically consisting of three team members) successfully completed their prototypes. The common reason for not completing the course was failure to complete the prototype designing and making in the time constraints posed by the course.

3. Qualitative analysis

We perform a qualitative analysis of the prototypes produced by students focuses on the creativity and ideation process. We want to identify the students' goals and analyse how they are achieved by the students, what the characteristics and stages of the idea generation process are, and how students reflect on this process. The main data for this analysis are the prototypes and the documentation adherent to these prototypes, which is written by the students. To this analysis, we add only some meta-evaluation of characteristics.

The successfully completed projects are listed in Table 1. The descriptions and goals or identified problems are self-reported by the students in their documentation. The prototypes are shown in Figure 1. To clarify the functionality of the prototypes, the inputs and outputs of each project, identified in the documentation, are listed in Table 2.

Table 1. Projects, descriptions and goals

	Project	Background of student team	Description (students' own description)	Goal of the project or identified problem
1	Alcolock	Biotech. / Computer engineering	A breathalyser-based restricted access container	Container to store items to which the user should not have access while under the influence of alcohol, such as car keys or certain medications
2	High-fiving polar bear	Education	A polar bear which recognises people passing by and raises an arm. When people high five with the bear, heart-shaped LED light on the bear's body turn on. Recognises people passing by and raises an arm. When people high five with the bear, heart-shaped LED light on the bear's body turn on.	Interactive object used to gain the attention and response of passers-by
3	Dancing robot	Education / Computer engineering	While pressing the button (or the hand approaching it) robot starts 'dancing', i.e. it starts to go around both to clockwise and counter-clockwise	Interactive object used to gain the attention of and interact with passers-by
4	BeerBot	Computer engineering	A robotic arm for the purpose of serving cans of beer from a cooler box. A button press will cause the arm to pick up a can and another button causes the arm to let go the can and return to its idle state	Arm for serving cans of beer from a cooler box

Table 1. Projects, descriptions and goals (continued)

	Project	Background of student team	Description (students' own description)	Goal of the project or identified problem
5	Activity Totem	Computer engineering	Sustained immobility - or sedentary behaviour - is an acknowledged issue both in the modern workplace as well as in the home. An alarm clock that, when set ON, will produce an alarm every 45-60 minutes. In order to turn it off, the user has to go to the device and complete a series of button presses	Activity gadget that prompts user to exercise at certain time intervals
6	Follow the line robot	*(High school students)*	Follow the line car	Car automatically moves along given line

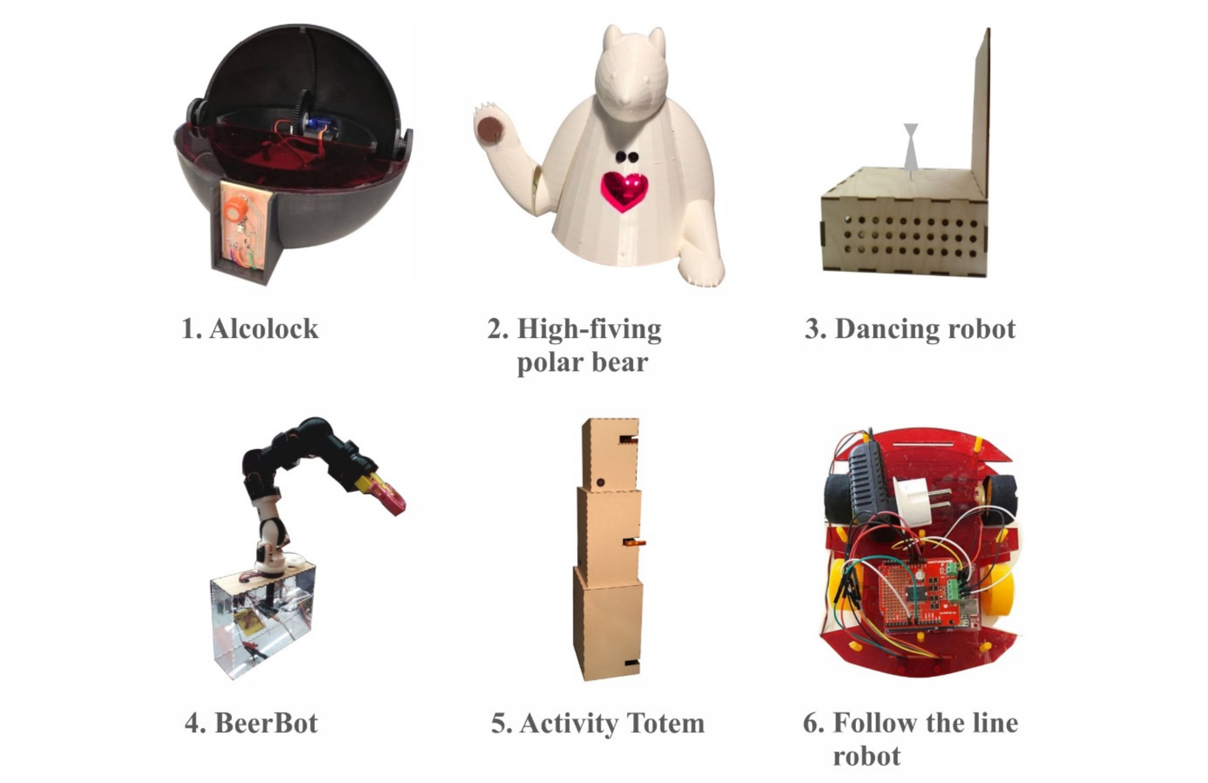

Figure 1. Prototypes at the end of the course

Table 2. Projects with realized inputs and outputs

	Project	Inputs (sensors)	Outputs (actuators)
1	Alcolock	Gas sensor and button	Servo
2	High-fiving polar bear	Proximity sensor and touch sensor	Servo and LED light
3	Dancing robot	Switch and potentiometer	Motor
4	BeerBot	Four optometers, pressure sensor, eight button sensors, distance sensor	Six servos
5	Activity Totem	Three proximity sensors	Three servos, LED strips and buzzer
6	Follow the line robot	Two follow the line sensors	Two motors

Major points from the students' own reflections are identified on the basis of the weekly diary of the project and summary of the documentation (Table 3). The qualitative analysis includes major idea generation stages identified on the basis of the documentation of each team (Table 4).

Table 3. Reflections on projects

	Project	Reflections (extracted from students' own description)
1	Alcolock	(1) lack of knowledge about servos, gears, and mechanical design; (2) division of tasks and split up the work amongst three team members; (3) working on specific tasks; (4) need of effective team communication; (5) document all activities as soon as they are done, and communicate these effectively
2	High-fiving polar bear	(1) modified the initial idea several times
3	Dancing robot	(1) to understand all related processes; (2) understand what actually need to learn during this course; need to learn a lot especially about programming and electronics; (3) making many mistakes; (4) own learning path
4	BeerBot	(1) couldn't quite keep up with the schedule that we had set for ourselves; (2) mathematics behind the movement of the arm proved to be a real challenge at first; (3) the way the automation needs to work in this arm made it scary to test at first; (4) if an electrical engineer joined us in this project would have helped a lot
5	Activity Totem	(1) the mini-workshop we had to discuss and brain storm was very interesting and could have easily spent more time on that part; (2) receiving advises (with amazing results); (3) learn parametric design; (4) don't do this in haste; (5) steep learning curve
6	Follow the line robot	(1) to make sure that size of each part is correct; (2) there are many steps in the design part – it is the hardest

Table 4. Projects and analysed idea generation characteristics

	Project	Idea generation stages	Degree of evolvement of the idea (degrees of low / moderate / high)
1	Alcolock	(a) container that restricts the user's access to its contents when under the influence of alcohol	Low: 2 similar alternatives
2	High-fiving polar bear	(a) combine first ideas; (b) Polar Bear, inspired by new-born polar bear baby, which wants to make high five with you (if you give high five without giving the 'fish' it will 'roar'.); (c) a polar bear coming out from the ice, took out the fish due to complexity	High: Combination of 3 ideas, out of 7 ideas in total (some similar with different level of detail)
3	Dancing robot	(a) simple idea – robot that starts 'dancing'	Low: 2 moderately similar alternatives
4	BeerBot	(a) a robotic arm serving cans of beer from a cooler box	Low: Single idea
5	Activity Totem	(a) activity gadget were to trigger and some level of interactivity; (b) pairs of sensors the users wear on their wrists and ankles and the task is only complete when the sensors have touched in a right sort of combination and often enough; (c) "plan B": one part concept involving a physical exercise (reaching up, crouching down) before the alarm shuts down (video illustrated the concept)	Moderate: 7 alternatives, one selected and developed
6	Follow the line robot	(a) Car automatically moves along the line	Low: Single idea

Overall degree of evolvement of the idea is judged on the basis of the idea generation stages and the idea generation described in the introductory part of the documentation. Idea generation stages are identified from changes of functionality (such changes range from removal or addition of functional feature [e.g. from Stages (b) to (c) of Project 2] to the selection of new and different function [e.g. from Stages (b) to (c) of Project 5]) following common approaches to analysis of idea generation (Puccio & Cabra, 2012).

4. Discussion

4.1. Identifying common obstacles for creativity in the context of digital fabrication

Exemplary projects

One of the observed obstacles was the provision of exemplary projects. An exemplary project found by team 6 influenced their project (the documentation by the team members followed the exemplary project). The provided exemplary project in the course also (partially) influenced Project 5 (the alarm aspect). Providing less emphasis on the exemplary project resulted in projects that are less related to the exemplary project in comparison with previous implementation (Georgiev et al., 2016).

Providing exemplary projects—whether or not similar to the selected project—has a dual effect on creativity. It may inhibit the overall creativity, especially if there is an attempt to replicate the exemplary project. On the other hand, albeit not so often, it may be beneficial for creativity if it is used to modify, combine, or transfer other ideas or as an inspiration in general.

Previous experience with digital fabrication and design fixation

The overall observed obstacle was design fixation. Particular cases of design fixation was previous experiences with particular digital fabrication activities, in addition to finding exemplary projects, and provision of exemplary project in the course. In some instances, having previous experience with particular digital fabrication activities resulted in mimicking the previously prototyped gadget, and could be considered as a cause of design fixation. For example, previous experience with digital fabrication activities influenced the creativity and idea generation of Projects 4 and 6. The team that built Project 4 reported previous experience with electronics and programming; this resulted in a project with greater complexity in the number of inputs and outputs, for example. The team that built Project 6 reported previous experience with prototyping vehicles. However, in some cases, having a previous experience with particular digital fabrication activities was useful for guaranteeing a good quality of the prototype (e.g. Project 2, where previous experience with programming Aurduino was useful for the prototype). Overall, previous experience can be seen as having a dual role in terms of creativity in the case of digital fabrication.

Skill threshold

Another obstacle is the skill threshold for different digital fabrication activities (e.g. skills needed for programming are greater than those for simple 2D design task [laser cutting]). In such cases, if the team needs to acquire a skill with higher threshold, this may reflect on the idea (e.g. in the case of Project 2, the idea was modified or simplified in relation to such an aspect). Skill threshold can be seen as having a complex interconnection with previous experience in different skills related to digital fabrication—2D design, 3D design, use of tools and machines, prototyping with electronics, and programming.

Commonality of inputs and outputs

The use of common inputs or outputs (sensors or actuators) is another possible obstacle to idea generation and consequently to creativity. For example, proximity sensor is a common sensor used in Projects 2 and 5, and it is used in a straightforward way (human proximity). However, this obstacle is closely related to skills that students already have in different digital fabrication activities and how much the project was 'simplified' in order to be realizable with the existing and newly-acquired skills in the available time frame.

The four types of obstacles identified here are based on the qualitative analysis of the team project (the prototype of interactive gadget and the documentation adherent to the designing and making of the gadget) in this study.

4.2. Identifying challenges for promoting creativity in digital fabrication

The following challenges are summarized on the basis of the identified obstacles:

- Previous experience has a dual role in terms of the creativity potential of the team members (individual and in combination). The challenge is to harmonize previous learning and skills of the different team members, because thee start with different skills in different backgrounds.
- Skills development during the course, particularly for skills that need the greatest degree of development, creates challenge of the team members (individual and in combination). The challenge is based on the varying learning speed among different members and processes. Students usually get quicker and better competence in processes that they mastered before.
- Fast materialization in FabLabs (Georgiev & Taura, 2015) is challenged by the need for iterations, trials, and (very often multiple) errors, in order to successfully deliver a functioning prototype.
- The degree of difficulty of the selected idea to be realized creates challenge for students to realize ideas with higher creativity. The challenge is the openness of the possible problem space and the fact that students are not initially aware of the effort of acquiring new skills might lead them to choose a too challenging project.

4.3. Identifying possible directions for solving these challenges

One of the commonly reported issues in the documentation was difficulty in learning certain digital fabrication activities (e.g. programming or design and fabrication of electronics [see Sánchez Milara et al., 2017]), although the overall learning process was perceived well. A possible solution to this lies in the way the teams are formed in the beginning of such digital fabrication class. Complementing the abilities of the members of the team and including at least one member who has with prior experience with programming and/or electronics will be beneficial for mitigating such issue.

Another solution to this challenge is to customize course content and learning to different backgrounds of students. This can be done, for example, by proving specialized lectures and profiled workshops for certain aspects of digital fabrication.

Finally, proving guidance to the team in the early stages of idea generation, with careful consideration of the backgrounds and what needs to be learned in order to realize the particular idea, may be beneficial for the creativity of the project outcome.

Limitations of this study include its small scale and lack of specific method to evaluate the identified obstacles.

Our further work on the topic will benefit from the data gathered in the planned larger scale course and in-depth analysis of the results in terms of the background of team members and what they have learned during the course. We plan to have team selection focused on multidisciplinary teams, customization of learning content, and tailored guidance.

5. Conclusion

Focusing on the case of a course in digital fabrication, we have explored the possible answers to the challenges for encouraging and promoting the creativity of the resulting prototypes. These challenges are identified as common obstacles for the creativity of teams of students in the context of the digital fabrication of prototypes, combining mechanical, electrical, and software components. In general, what has to be learned in the limited time of a digital fabrication course, compared to what is already known in the different disciplines of digital fabrication, influences idea generation, idea evolution, and creativity.

Acknowledgement

The authors would like to thank the students of the digital fabrication course. This work is partially funded by a 2017 strategic action of the Faculty of Information Technology and Electrical Engineering of the University of Oulu “SA-18: Exploiting Fab Lab as an Active Educational Platform”.

References

Analytis, S., Sadler, J. A., & Cutkosky, M. R. (2015). Creating Paper Robots increases designers’ confidence to prototype with microcontrollers and electronics. International Journal of Design Creativity and Innovation, 1–12.

Blikstein, P. (2013). Digital Fabrication and ’Making’ in Education: The Democratization of Invention. In J. Walter-Herrmann & C. Büching (Eds.), FabLabs: Of Machines, Makers and Inventors.

Carrington, P., Hosmer, S., Yeh, T., Hurst, A., & Kane, S. K. (2015). “Like this, but better”: Supporting novices’ design and fabrication of 3D models using existing objects. In Proceedings of iConference 2015.

Georgiev, G.V., & Taura, T. (2015). Using idea materialization to enhance design creativity. In Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. 8: Innovation and Creativity, July 27-30, Milan, Italy, pp. 349-358.

Georgiev, G.V., Oja, M., Sánchez, I., Pyykkönen, M., Leppänen, T., Ylioja, J., van Berkel, N., & Riekki, J. (2016). Assessment of relatedness to a given solution in 3D fabrication and prototyping education. Proceedings of the Fourth International Conference on Design Creativity (ICDC 2016), November 02-04, Atlanta, Georgia, USA.

Howard, T. J., Culley, S. J., & Dekoninck, E. (2008). Describing the creative design process by the integration of engineering design and cognitive psychology literature. Design Studies, 29(2), 160–180.

Linsey, J. S., Tseng, I., Fu, K., Cagan, J., Wood, K. L., & Schunn, C. (2010). A study of design fixation, its mitigation and perception in engineering design faculty. Journal of Mechanical Design, 132(4), 041003.

Martin, L. (2015). The promise of the Maker Movement for education. Journal of Pre-College Engineering Education Research (J-PEER), 5(1), Article 4. doi: 10.7771/2157-9288.1099

Oman, S. K., Tumer, I. Y., Wood, K., & Seepersad, C. (2013). A comparison of creativity and innovation metrics and sample validation through in-class design projects. Research in Engineering Design, 24(1), 65–92.

Principles of Digital Fabrication course, 2017 <https://wiki.oulu.fi/display/PDF/>

Puccio, G. J., & Cabra, J. F. (2012). Idea generation and idea evaluation: Cognitive skills and deliberate practices. In Mumford, M. D. (Ed.) Handbook of Organizational Creativity, pp. 189-215, Waltham, MA: Academic Press.

Rhodes, M. (1961). An analysis of creativity. The Phi Delta Kappan, 42(7), 305–310.

Sánchez Milara, I., Georgiev, G.V., Riekki, J., Ylioja, J., & Pyykkönen, M. (2017). Human and Technological Dimensions of Making in FabLab, The Design Journal, 20(sup1), S1080-S1092.

Sheridan, K. M., Halverson, E. R., Litts, B. K., 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.

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 (IJDLDC), 7(1), 33-49.