

Human and Technological Dimensions of Making in FabLab

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Abstract: In this research, we studied the human dimensions of experience and knowledge, confidence, motivation, and fun with regard to four technological dimensions referring to a FabLab environment: 2D and 3D design, tools and machines, prototyping with electronics, and programming. An intensive, two-week training period for high school students in digital fabrication and design was utilized as a testbed to evaluate how the participants modified their perception of the four human dimensions during the training. We identified that prototyping with electronics and programming were the most significant obstacles. In addition, the perception of acquired knowledge and confidence had increased considerably after training except for the programming domain. FabLab trainers can utilize the trainees' perceptions on different dimensions to emphasize the specific design aspects of the activity in order to achieve the training goals. We also expect that a detailed description of the experiment setup can be useful to other researchers and practitioners while organizing activities at FabLab.

Keywords: FabLab, digital fabrication, motivation, confidence, experience, fun, creativity

1. Introduction

Fabrication Laboratories (FabLabs) and digital making have proven to spark the creativity, the imagination, and the motivation to create (Analytis et al., 2017; Georgiev and Taura, 2015; Strickland, 2013). The phenomenon of digital making poses new research challenges in terms of the interactions between humans and technology (Gershenfeld, 2012; Grover et al., 2014). Scholars and educators have reported a variety of positive outcomes from the 'Maker Movement' as a forefront instructional process (Papavlasopoulou et al., 2016). FabLabs are considered from various standpoints, from new educational environments to a global social movement (Blikstein, 2013; Blikstein and Krannich, 2013; Walter-Herrmann and Büching, 2014). Moreover, FabLabs also serve as spaces where creative production takes place from perspectives of art, science, and engineering as users blend digital and physical technologies to explore ideas, learn skills, and create (Sheridan et al., 2014).

The foundation of FabLabs resides in the belief that the most sustainable way to bring the most significant results of the digital revolution to developing communities is to enable them to participate

in creating their own technological tools for finding solutions to problems (Mikhak et al., 2002). In terms of culture, a considerable challenge faced by FabLabs involves finding the most effective ways to give the new users the opportunity to gain a wide range of skills in various environments and communities with which they could take full advantage of all the tools in FabLabs (Mikhak et al., 2002).

The existing work also points towards the fact that only few students have knowledge of digital fabrication (Hjorth et al., 2015). Students lack the knowledge of design processes and most of them do not act on their creative ideas (Hjorth et al., 2015). In fact, very few students act towards and realize an idea for a product or an invention that they had thought of. Such observations point towards a complexity of related opportunities and issues for creating in FabLabs. Moreover, the utilization of FabLabs in facilitating formal education is a recent trend; therefore, so we require new frameworks and methodologies in order to maximize the acquisition of new skills in FabLab environments. Among the different types of learning methodologies, training in FabLab applies to project-based learning and provides work-like experiences (Slåttsveen, 2016; Bekker et al., 2015).

To better understand the complexity of applying digital fabrication in learning environments, in this study we investigate the human dimensions of experience and knowledge, confidence, motivation, and fun in the FabLab context, and compare these dimensions with the technological dimensions of 2D/3D design, tools and machines, prototyping with electronics, and programming. We utilize a two-week design and prototyping training period in our FabLab as a testbed.

2. Dimensions

In this study, we examine four human dimensions concerning digital fabrication within the FabLab context:

1. *Experience and knowledge.* This dimension refers to the set of abilities or skills to perform tasks referred to in certain technical domains.
2. *Confidence.* This dimension has a relation with self-esteem. It indicates the assurance of the person while starting an activity on their own.
3. *Motivation.* This dimension refers to having a reason or being eager to perform a particular activity.
4. *Fun.* This dimension refers to the hedonic benefits experienced while performing a particular activity (Hassenzahl, 2003).

In this paper, we explore how these human dimensions intersect in complex ways with the technological dimensions, corresponding to the typical activities in FabLab. The technological dimensions considered are as follows:

1. *Designing 3D and 2D parts.* This dimension incorporates the software and other tools which are utilized to design two-dimensional parts, such as those that are typically cut with a laser cutter, or 3D parts, such as those typically designed to be 3D printed. Following FabLab principles, this dimension typically relies on open source software.
2. *Prototyping with electronics.* This dimension incorporates hardware design (electronics schematics and layout design), their fabrication and soldering the components. In FabLab we use a CNC-milling machine to create the circuit on a copper plate.
3. *Programming.* This dimension incorporates the basic programming of embedded systems with a high-level programming language.

4. *Utilizing the tools and machines at the FabLab.* This dimension incorporates the use of FabLab infrastructure to make a particular prototype. It includes the utilization of the vendor's software to operate the machines.

3. Experiment setup

3.1 Summer training description

We utilized intensive summer training for high-school students in digital fabrication, design and prototyping hosted at the FabLab in our university as a testbed to evaluate human and technological dimensions, both before and after the training (Figure 1). We hired the trainees through a financial programme that our city offers to stimulate summer jobs among youngsters. At the beginning of the training period, we explained to the participants that they were not our students, but that they were university employees. We expected with this statement to increase the autonomy of the kids, assuming that they would not consider us facilitators as teachers, but as senior colleagues. We hired 14 high school students (15–18 years old) from the 30 applicants across local schools. The total training time spanned 60 hours, distributed across two weeks.



Figure 1. Fabrication, design, and prototyping during summer training (top from left to right: team discussion, preparing a 2D-cut part for electronics; bottom: 3D printing of a part, electronics preparation).

During the training period, the youngsters had to design and build a fully functional alarm robot. This robot was to start making noise and move away at a programmed time. The ‘sleepy user’ was supposed to catch and shake the robot in order to switch off the alarm (Figure 2). We divided the participants into four groups of three to four people, each. The assignment was the same as one proposed in one of our university courses (Principles of Digital Fabrication) for undergraduate students. They had access to Arduino boards, a set of electronic components (DC motors, buzzers, servos, etc.), and our FabLab machines. Since the activity possessed a formative perspective, the trainees always had support staff to assist them whenever they had any problems. Two researchers (who also organized the activity; one of them being one author of this paper) and three

undergraduate students constituted the staff. In order to help teenagers to organize their time, we proposed four different milestones: (1) robot design and low-quality mock-up, (2) electronics, (3) mechanics, and (4) Arduino programming, which match the technological dimensions we had presented in Section 2. Before work on each milestone, the support staff gave a short practical introduction to the topics, placing emphasis on the software design tools and the recommended processes. Table 1 presents the main software tools utilized to support the four technological dimensions.



Figure 2. Early prototypes (from left to right: an owl, a frog, a foot, and a UFO).



Figure 3. Robots created during the summer training (from left to right: an owl, a frog, a foot, and a UFO).

Table 1. Main software tools utilized during the training

Technological dimensions			
2D/3D design	Electronics	Programming	Utilization of devices
Inkscape Autodesk 123 Design FreeCAD	Autodesk Eagle	Arduino IDE	Fabmodules and specific software drivers from machine vendors

All groups but one managed to have a working prototype at the end of the two-week period. One of the three succeeding groups did not manage to have a fully multitask operational robot. The fourth group had everything ready, but could not complete the integration of mechanics, electronics, and code. The resulting prototypes exhibited different levels of creativity, ranging from more

conventional to more original in terms of appearance and functionality, therefore, expressing the fun-factor in design (Figure 3).

3.2 Questionnaires and essays

In order to study how the training modified the participants' perception of the four human-dimensions, they answered a survey with 16 questions (one per human-dimension/technological-dimension pair) both before and after the training. For instance, we wanted to know how their perception of motivation (human-dimension) has changed across the four technological-dimensions (2D/3D design, electronics, programming, and tools usage). The perception of the 16 different combined dimensions was measured using a 5-point Likert scale. The questions required answers on the scale, ranging from strongly disagree, disagree, neutral, agree, to strongly agree. A random number identified the participants in order to ensure their anonymity.

In addition, for a qualitative analysis, we asked each team to write a short essay containing a reflection on their work. Both, the participation in the survey and the participation in the final reflection, were voluntary tasks.

These perceptions and reflections on the different dimensions can provide insights into specific design aspects of the activity in order to achieve the training goals. Furthermore, the perceptions and reflections are relevant in organizing activities at the FabLab.

4. Results

4.1 Perceptions before and after the training

From the 14 participants, we received 11 valid answers ($N = 11$). We discarded the surveys of three participants because they did not answer all the questions in both surveys. In order to analyse the data, we opted to use the median and the mode as our measures for central tendency, instead of the average. Many authors advise against using the average as a method to analyse data derived from Likert scales (Jamieson, 2004). Figure 4 contains a visual representation of the participants' median perception in each technological and human dimension before and after the training while Figure 5 represents the mode for the same measurements.

According to the figures after the training, students had a very positive perception of the four human-factors analysed in the four technological dimensions. They agreed or absolutely agreed that they had developed high confidence to start an activity on their own, and high motivation to start future tasks in the four technological dimensions analysed. The technological dimensions that increased the motivation of students were electronics and the utilization of tools in the FabLab. In addition, they agreed or strongly agreed with the fact that they have had fun in performing tasks associated to the four technological dimensions. Again, they seemed to have more fun in prototyping with electronics and utilizing the FabLab equipment. Finally, they agreed or strongly agreed about having acquired a high degree of knowledge with respect to the aspects related to the four technological dimensions.

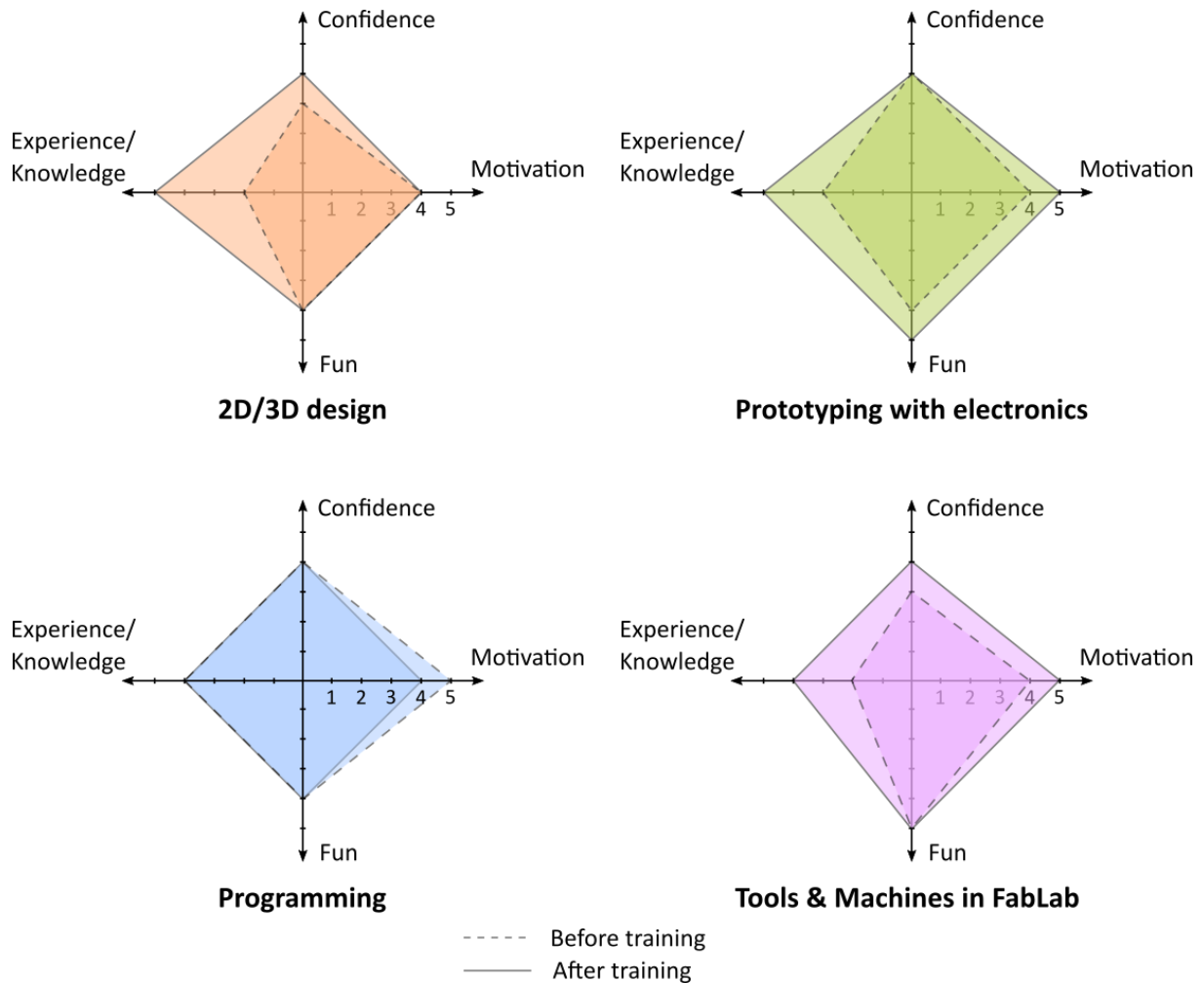


Figure 4. Median reported values before and after the training period for the four human dimensions and four technological dimensions ($N = 11$).

In order to test our assumption of the training's positive influence on the students' perceptions in the four human dimensions, we conducted a Wilcoxon signed rank test to compare the answers in the conditions before the training and after the training. We opted for a non-parametric test because of the ordinal nature of the values of the Likert scale (Jamieson, 2004). All the differences and their significance are reported in Table 2.

The results from the questionnaires demonstrated that the participants either improved or at least maintained their perceptions in the different domains after the training weeks. The only exception was observed in the case of programming. In this case, the median decreased by one point for motivation, and the experience/knowledge also reduced by one point.

The increase in the experience/knowledge in all technical domains except programming is especially relevant. The Wilcoxon signed rank test presents a statistically significant difference in six out of 16 combinations. We do not have any accurate information about the perception changes in motivation and fun in any of the four technological dimensions or in any of the human dimensions related to programming.

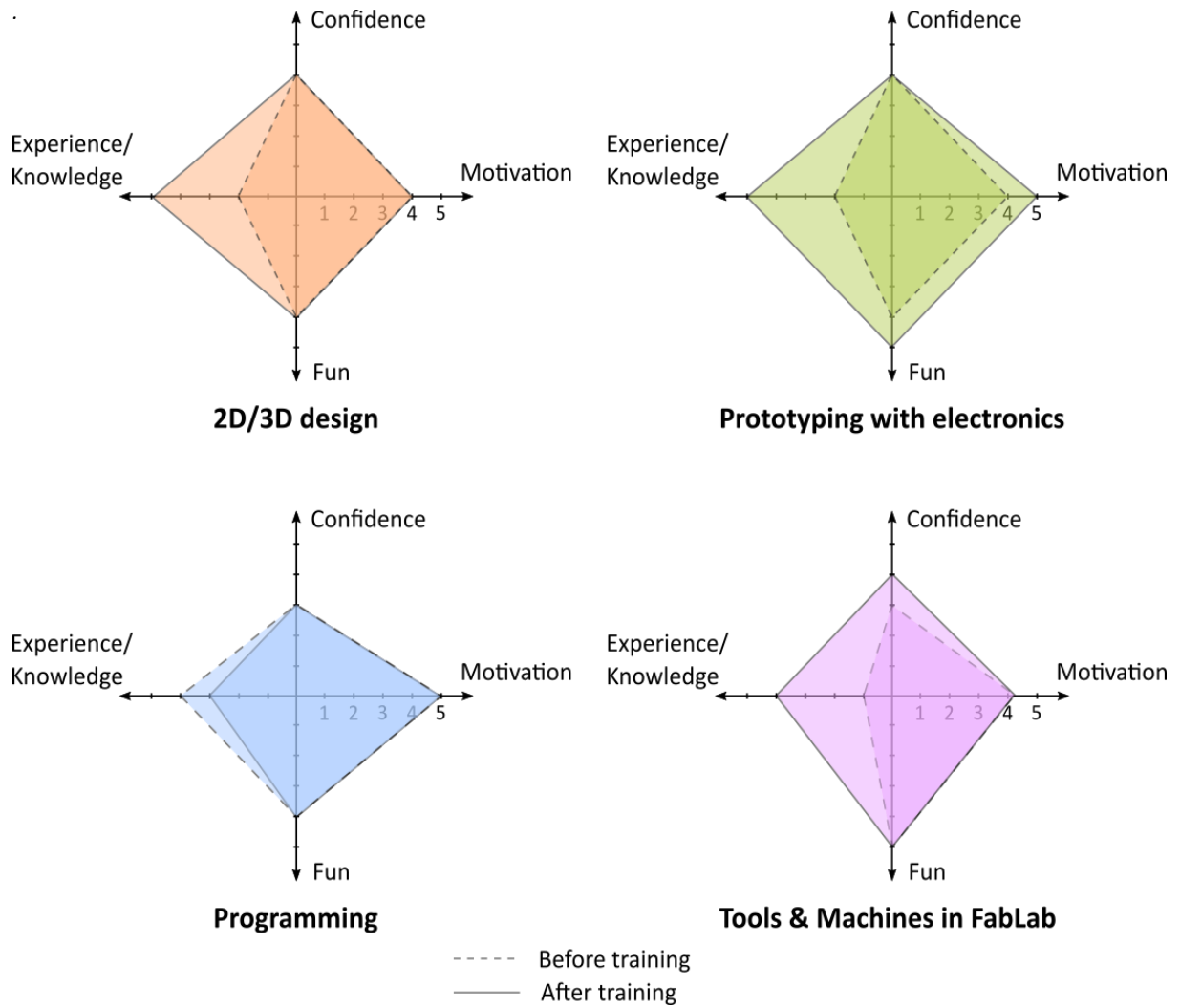


Figure 5. Mode reported values before and after the training period for the four human dimensions and four technological dimensions (N=11).

Table 2. Differences of answers before and after the training period (degrees of freedom 10; results with $p < 0.05$ are marked with *; results with $p < 0.01$ are marked with **).

Human dimensions	Technological dimensions			
	2D/3D design	Electronics	Programming	Utilization of devices
Experience/ Knowledge	V = 0 p = 0.003**	V = 0 p = 0.008**	V = 7 p = 0.240	V = 0 p = 0.003**
Confidence	V = 0 p = 0.002**	V = 3 p = 0.036*	V = 5 p = 0.279	V = 3.5 p = 0.013*
Motivation	V = 10 p = 1.000	V = 18 p = 1.000	V = 18.5 p = 0.104	V = 7 p = 0.484
Fun	V = 3 p = 0.119	V = 16 p = 0.821	V = 15 p = 0.374	V = 5 p = 0.571

4.2 Trainees' reflection

We collected the reflection reports of the three groups (11 trainees in total). One of the groups did not provide their personal feedback as this procedure was voluntary. Each group wrote one essay, which reflects the consensus of the whole group. However, certain members pointed out individual opinions in some cases. All three essays demonstrate a positive view of the experience in spite of the challenges encountered. The training met the expectations of the participants; here is a snippet from the feedback of Team 2: *'Most of our expectations for the training were met. We got to do all the things we wanted, even if they didn't work.'* All the groups remarked that they would recommend this kind of experience to other pupils of the same age; this is a snippet from the feedback of Team 4: *'[W]e haven't had possibilities before to do programming or make circuit boards in school or anywhere else.'* The participants also emphasized that they had acquired quite a lot of new skills in the two-week period; a snippet from the feedback of Team 1 follows: *'We've learnt how to use different software and gadgets like 3D printer, laser cutter and milling machine. Also, Arduino coding was new for the most of us.'* In addition, the groups also mention that they acquired some extra skills, which were not included in the studied dimensions; as seen in a snippet from the feedback of Team 1, these include active learning and collaboration: *'[W]e all agree that we learnt a lot; not just about technology but also about teamwork and working more independently without the constant guidance of an adult.'*

5. Discussion

5.1 Perceptions: Experience and knowledge acquisition

Participants agree that they have improved their knowledge in three out of four technological dimensions with statistically significant results. These dimensions are 2D/3D design, electronics, and utilization of tools and devices. This suggests that the trainees really perceived that they have acquired considerably new knowledge during the two-week training period. The results of the questionnaire match the comments derived from the reflection essays; for instance, in their reflection essay, Team 2 claimed: *'All of us learnt a lot here.'* The increase in the perceived knowledge of 2D/3D design is particularly important. The participants believed that they mastered a large number of aspects of 2D design (median of 5) after starting from very basic knowledge (median of 2). The essays, however, reflect that the process was sometimes challenging for the participants; a snippet from the reflection essay of Team 1 reveals that *'3D models were hard to use and sometimes it was very frustrating to edit the models.'* On the other hand, the 2D/3D design was the technical domain that required less support from the instructors. We believe that the software tools selected in this technical domain enabled a self-exploration of the trainees, empowering active learning (Meyers et al., 2003). The tools utilized in the other technical domains did not enable this self-exploratory approach very easily, perhaps, because the theoretical concepts that were considered are less intuitive and require more guidance.

On the other hand, programming is the only technical domain in which the participants did not perceive an increase in their knowledge (in fact, Figure 5 shows a reduction of one point in the mode). Although the differences are not statistically significant (Table 2), the instructors perceived several difficulties during training. Only one of the groups managed to write their own code by themselves (programming dimension). The other three groups needed a lot of support from the instructors. We believe this was a consequence of the trainees' lack of previous experience in programming, although the participants had claimed that they had programming skills (median 4 in Figure 4) in the initial questionnaire. The fact that many of the participants only had HTML skills, and

that they may consider HTML a programming language, may explain this inconsistency. The trainees had to work with a proper programming language (Arduino C version) after a short one-hour introduction. This little training is not enough for average students to start programming by themselves. Based on the experiences of this test, we believe that programming is one of the most challenging aspects for trainees visiting the FabLab for the first time. Hence, we recommend starting with a hands-on guided tutorial, which presents the basic principles of programming using Arduino IDE. Additionally, we recommend utilizing Scratch¹ like visual programming languages such as S4A² or Snap for Arduino³ for absolute beginners.

5.2 Perceptions: Confidence

Statistical data demonstrates that the level of confidence in trainees has increased to start 2D/3D design projects and operate FabLab machines after the training period. This makes sense as they have considerably improved their skills (Section 5.1). Others authors have already suggested that digital fabrication increases confidence as appealing and functional prototypes can be built more quickly in comparison to other methods (Blikstein, 2013; Analytis et al., 2017).

In addition, the pupils had the same level of confidence as before (while working with electronics), even while they perceived that they had acquired new skills (Section 5.1). This might indicate that electronics is a challenging domain for newcomers. While they might have some basic skills, as soon as they acquire new expertise in a field, they become aware of the gaps in their knowledge. However, we believe our approach has worked quite well. In order to acquire knowledge in electronics we recommend designing a basic Arduino shield for a robot, using a minimum set of components, and with reduced functionality.

5.3 Perceptions: Difficulty level of the different technological dimensions

Based on the confidence results (Section 5.2), and in combination with the results of Section 5.1, we can order the four technical domains according to the perceived difficulty level (Figure 6).

5.4 Perceptions: Motivation

With the motivation dimension, we wanted to evaluate how likely a participant is towards starting a project in any of the four technological dimensions by virtue of their own initiative. We did not obtain statistically significant results. The qualitative analysis of the essays, however, present a very positive attitude of the trainees to starting their own projects in the future; a snippet from the essay written by Team 1 reveals the following: *'[B]ut now that we know what we are able to do here we will definitively come back.'* This is consistent with the absolute high values given to motivation after the training period, which contained median values over four in all technical domains.

Although not significant, there is a decrease in motivation for programming. We would need to confirm this observation in future experiments. We think that the negative change in motivation, however, might be caused by high initial expectation (median value of 5 in Figure 4). When the participants realized that programming was more challenging than that they initially expected, the motivation decreased. In addition, this also confirms that programming has the highest level of difficulty for newcomers (as stated in Figure 6).

¹ <https://scratch.mit.edu/>

² <http://s4a.cat/>

³ <http://snap4arduino.org/>

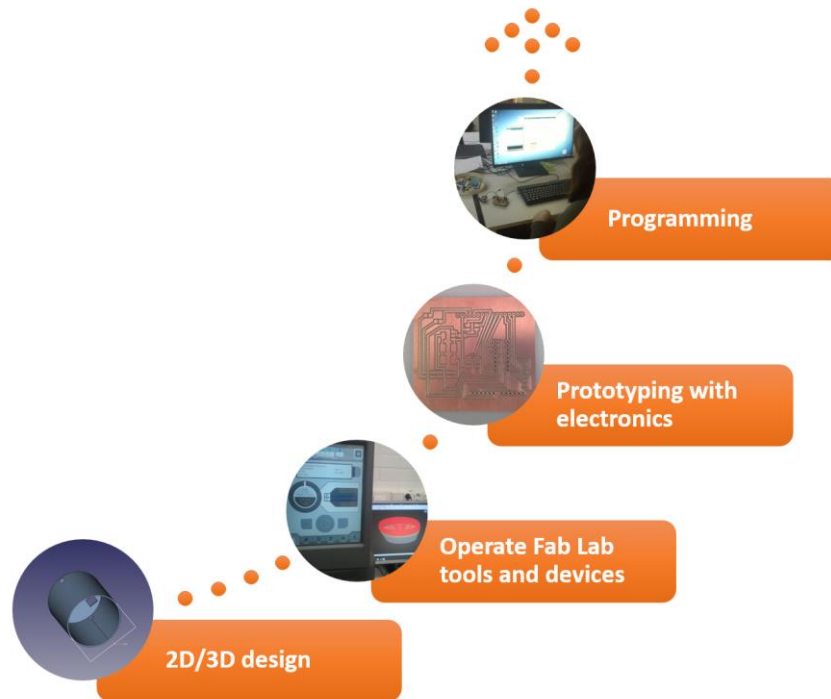


Figure 6. Perceived difficulty level based on the skills acquired and the perceived confidence. 2D/3D design is the least challenging human dimension, while programming is the most challenging one.

5.5 Perceptions: Fun

The two technical domains that the participants found most enjoyable were operating the FabLab machines and prototyping with electronics—thee domains in which they had to work with tangible objects, rather than software tools. Tangible interaction has often been linked to an improved user experience in relevant literature, which in this special issue is described under the umbrella term of ‘fun’ (Zaman et al., 2016). We, therefore, recommend orienting tangible activities to build a concrete item quickly, and through successive iterations, adding more features and functionality.

The qualitative analysis shows that the difficulty of the tasks should not be negatively correlated with enjoyment; the ideal balance is expressed in a snippet from the essay composed by Team 2: ‘3D-modelling was punishing, but fun, even if I [the writer of this paragraph] had experience in it.’

5.6 Insights and implications

The statements of the students indicate some of the issues that they encountered during training. For example, the following statement, ‘At start it was fun, but when everything started to fail, it brought the spirit down’, points towards the importance of motivation and spirit in digital fabrication, especially in the context of the team. On the other hand, the fun factor is emphasized in a predominant number of responses; for example, responses from Team 1: ‘I had a lot of fun and I learned a lot’ and ‘It’s been lots of fun and the training has been really comprehensive!’

There were observable differences between the members of each team, both, in terms of human dimensions and technological dimensions; this suggests the importance of team creation and how learners collaborate inside them. When compared with a recent course on 3D fabrication and prototyping for university students (Georgiev et al., 2016), these results suggest that prior experience seems to have a considerable effect on the results of prototyping and their creativity.

Considering a broad perspective on how these findings can be used, the implications for recruiting and training can be outlined. For example, if something is already considered ‘fun’ before trial, it can be used in student recruiting. An improvement of future training activities by focusing on the dimensions with insufficient progress is another implication of these findings.

5.6 Limitations

We are aware that the population sample was too small ($N = 11$) to have conclusive statistical data. We believe, however, that the results were significant enough to initiate a discussion on the most relevant dimensions that affect users’ perceptions while running instructional activities within FabLab environments as well as the relationship among them. Furthermore, many of the statistical results are supported by qualitative data derived from the participants’ reflection surveys.

6. Conclusion and future work

In this paper, we present the results of a two-week summer training period in which pupils between the ages of 14 and 18 developed their own robot gadget from scratch (this includes the pertinent electronics and robot mechanics). We analysed the results on the basis of four technological dimensions (2D/3D design, programming, electronics, and utilization of devices and machines) and four human dimensions (experience/knowledge, confidence, motivation, and fun). In order to collect the pupils’ perceptions in the 16 combinations of dimensions, they filled in a pre-training and a post-training questionnaire. In addition to these, also wrote a free form reflection essay about their experiences. The findings shed light on the paradigm of digital making that influences how we think, ideate, do, make, and create in the contemporary digital landscape. In addition, the results of this study provide some design implications for FabLab trainers, supporting them in the preparation of training activities. Trainers can utilize the relations discovered among the different dimensions to emphasize on specific design aspects of the activity in order to achieve the training goals. Moreover, we have arranged the technological dimensions, utilizing the perceived difficulty as the sorting criterion. 2D/3D design turned out to be the simplest domain, followed by the utilization of machines; electronics and programming were identified as the most challenging technological domains for newcomers at the FabLab.

We are planning to continue this research in the future. We will develop further studies by scaling up the courses and participation. This will include different modes of delivery, different audiences, and different time-frames, thereby improving the making activities based on the feedback and findings of the current study. For instance, during spring 2017 we will run a similar experiment with an official university course targeted to first year students of all degrees in our university. We expect around 20 students in that course. This study will include a new dimension: students’ expectations on the different dimensions. In addition, we are planning to evaluate also the creativity and complexity of the final products. Our final goal is to create a framework that helps instructors organize activities in FabLabs based on the initial knowledge, the skills and the expectations of the participants.

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