Digital Technology and design processes II: Follow-up report on FabLab@School survey among Danish youth

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AARHUS UNIVERSITY

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1. Executive summary

This report is part of the FabLab@School.dk research program, which investigates the use of digital fabrication technologies and design activities among students aged 11-15 years in Danish schools. In order to measure the effects of the FabLab@School.dk educational program from 2014 to late 2016, this follow-up survey was administered to two groups: first, schools in which FabLab and design activities had been carried out in the FabLab@School.dk project throughout a 2-year period (FabLab schools), and second, a control group of schools that were not part of the FabLab@School.dk project (control schools). The survey reported here, is a follow-up to a similar survey conducted in the fall of 2014. The present survey was conducted in the fall of 2016 among 246 students from FabLab schools and 203 students from control schools, totaling 449 students. The students answered 111 questions, which probed their use and knowledge of digital fabrication technologies, both in and out of school, their knowledge of design, and their perspectives on the issues of hacking, open data and privacy. The sample of students in this survey was not randomly selected, and thus we cannot claim representativity. This means that claims are made for the sample only. Below is a summary of the most important findings for this sample of students from the four participating municipalities.

FabLab students improved their understandings of digital fabrication technologies

Compared to the 2014 group, the FabLab group on average had an increase in self-perceived knowledge of 3D printers, laser cutters, vinyl cutters, building electronic devices, microcontroller boards, programmable robots, text-based programming, and blockbased/visual programming.

FabLab students gained experience with a range of digital fabrication technologies

Students in the FabLab group had been exposed to more digital fabrication technologies, than was the case in the control group. Further, the FabLab students had more experience in using the technologies to work on own ideas, and they had to a higher degree worked with the technologies in school settings.

FabLab students found the work with digital fabrication technologies motivating

On average, FabLab students agreed that the work with digital fabrication in their schools had been interesting and useful for their futures. They “liked” FabLab, “loved projects with digital fabrication”, and “learned a lot.”

Learning outcomes and motivation were very dependent on schools and teachers

There were large variations within the FabLab group with regard to the number of technologies used, design process structuring, student motivation, and students’ self-perceived knowledge, as well as on self-perceived learning outcomes such as creativity with digital fabrication technologies, abilities to critically reflect on the use of digital technologies, and complex problem solving. The variations among groups of schools followed a pattern in which higher numbers of technologies, more knowledge of the design process model, higher motivation, and better learning outcomes appeared to be connected.

The FabLab@School.dk has initiated Design literacy among students

In schools in which students used a wide range of technologies, worked with own ideas with a diverse range of digital technologies, and had their work scaffolded and structured around the AU Design Process Model to a high degree, students reported that they had on average become better at imagining change with technology, at working creatively with technology, at understanding how new technologies are created, and at understanding how technology is affecting our lives as well as at solving complex problems. Thus, the FabLab@School.dk project did initiate the development of Design literacy among some students. However, it was very much up to chance, what education in digital fabrication and design processes, the students received.

2. Foreword

This report is part of the FabLab@School.dk research program, which investigates the use of digital fabrication technologies and design activities among students aged 11-15 years in Danish schools. In order to measure the effects of the FabLab@School.dk educational program from 2014 to late 2016, this follow-up survey was administered to two groups: first, schools in which FabLab and design activities had been carried out in the FabLab@School.dk project throughout a 2-year period (FabLab schools), and second, a control group of schools that were not part of the FabLab@School.dk project (control schools). The survey reported here, is a follow-up to a similar survey conducted in the fall of 2014. The present survey was conducted in the fall of 2016 among 246 students from Fablab schools and 203 students from control schools, totaling 449 students.

We would like to thank all the participating schools as well as the collaborating municipalities of Aarhus, Silkeborg, Vejle and Favrskov. We would also like to thank Martin Thorhauge for help with the charts and Mathias Milter Liboriussen for support with statistical analysis. Lastly, a special thanks to the control schools, which were not obliged to participate in the project but nonetheless found the time and resources for us to carry out our survey among their students.

We have experienced problems in printing this report directly from internet browsers. We therefore recommend printing from a dedicated pdf reader such as Adobe Reader, Apple Preview or Foxit Reader.

3. The FabLab@School.dk survey

FabLab@School.dk is a Danish research project at the Department of Aesthetics and Communications at Aarhus University supported with a grant from The Danish Industry Foundation. It is part of the global FabLab@School initiative, founded by Dr. Paulo Blikstein at the Transformative Learning Technologies Lab at Stanford University. The Danish research project focuses on FabLabs as "hybrid learning laboratories, which combine digital fabrication, design thinking, collaborative idea generation and creating in solutions to complex societal challenges" (Smith, Iversen, & Hjorth, 2015). This definition of FabLab@School places an emphasis on the entire design process—from early ideation, sketching, and mockup creation to the initial presentation of a prototype.

The survey reported here was conducted in collaboration with Stanford University. Parts of the survey have been run in various countries worldwide in order to establish the foundations for comparison on a global scale. Aarhus University is cooperating with Aarhus, Vejle and Silkeborg municipalities in the FabLab@School.dk educational project.

The survey is in part based on questions used by TLTL at Stanford University (Blikstein, Kabayadondo, Martin, & Fields, 2017). The questions reported here are translations, often abbreviated, of the Danish questions. A list of full length translations can be found in the Appendix together with the original questionnaire in Danish. Some of the survey items are tentative measures that are currently guiding our further investigations but are not yet established as valid measures of the traits concerned. This report is mainly descriptive in its approach to the collected data: it serves the purpose of presenting the data in a way, that lends itself to further exploration. In addition to the survey reported here, the research project consists of ethnographic observations and interviews with teachers and students, as well as design interventions in and with the collaborating schools.

3.1. Digital fabrication

In this report, as in the survey, we use the term "digital fabrication" to denote the use of a wide range of digital technologies with the aim of creating physical products. As is customary within the emerging research field of digital fabrication in education, such technologies include, but are not limited to, 3D printers, laser/vinyl cutters, and CNC routers. We also include programmable robots, microcontroller boards, and other means for creating physical computing products.

3.2. Content and limitations of this report

The report describes frequencies of responses to questions. It also goes further in tentatively exploring composite measures and differences between groups of schools. The findings of the report are divided into themes, which are explored from various different perspectives with various types of questions. In chapter four, students' use and knowledge of digital fabrication technologies is explored. Chapter five concerns the students' design knowledge, while chapter six reports on student motivation in work with digital fabrication. Chapter seven is the conclusion, which is followed by a list of references and an appendix containing the original questionnaire, translations into English of all the questions, charts showing the number of responses for every quantitative question asked on the report, and details with regards to statistical tests, which have been run on the data.

3.3. Research question

The main research question guiding the Danish FabLab@School research project, was:

How can design thinking and digital fabrication in Danish public schools contribute to adolescents' abilities to understand and create with digital technologies?

3.4. The Danish FabLab@School project

As stated above, this survey is part of an ongoing research project on digital fabrication in education. In 2014 the educational landscape in Denmark changed due to a new reform of standards in the Danish public schools (age six to 16). Part of the initiative was to introduce a stronger focus on competencies related to 21st century skills (Ananiadou & Claro, 2009). On this basis, The Danish FabLab@School project was initiated by the Child-Computer Interaction group at Aarhus University, in collaboration with the municipalities of Aarhus, Vejle and Silkeborg, to study how digital fabrication could promote 21st century skills in educational contexts. The aim of the FabLab@School project was and still is to develop a sustained initiative promoting digital fabrication in education within the existing framework of the Danish school system among children aged 11 to 15.

Among the 21st century skills that were considered relevant to the above-mentioned combination of digital fabrication, design thinking, collaborative idea generation and creating in solutions to complex societal challenges, were two sets of abilities:

- Abilities to use, master and understand digital technologies
- Abilities to think and act innovatively (with technology) on societal challenges

It was and is a central hypothesis of the research project that adolescents aged 11 to 15 years can improve these abilities significantly through hands-on education with digital fabrication technologies compared to existing provision in the Danish school system. It was a further hypothesis that students who had not participated in the FabLab@School.dk project would not have developed these abilities to the same extent as students who had worked with design and digital fabrication technologies.

3.5. Research design

As stated, our hypotheses were investigated through observations, interviews, and interventions, as well as by the survey presented here. In 2014 we conducted a baseline survey of 1,156 students exploring their use, knowledge of and abilities in regard to digital technology and design, as well as their attitudes to the issues of hacking, open data, and privacy. This report presents a follow-up endline survey which was conducted in late 2016 with the purpose of assessing improvements among students who had been educated in design and digital fabrication as part of their involvement in the FabLab@School.dk project. The research design resembles an experimental design: a test group (FabLab schools) and a control group (control schools) are followed in order to look for differences in their development. However, because the project was conducted in the messy context of real-world schools, this was not what is sometimes referred to as a controlled experiment. Rather, it resembled a quasi-experimental setup with great variations between schools, teachers, and implementations. Further, it was not possible to follow the same students throughout the study period. Too many of the students had graduated from school by the time we conducted the follow up study for this to be possible. However, we did specifically ask the participating FabLab schools for students, who had been a part of the FabLab@School.dk project activities, so that they could be compared to students from the control schools and to the students in the baseline survey.

Compared to the baseline survey of 2014, the endline survey, reported here, featured a smaller number of questions, for two reasons. First, in 2014 we witnessed some fatigue among students and we wished to avoid this; and second, some of the questions in the original 2014 survey had been included to probe students' use and understanding of technologies in general. Since we did not hypothesize change in their relationships with technologies other than digital fabrication technologies, we did not include such questions in the endline survey reported here.

Concurrently with the survey, we performed interviews with 11 groups of students (2-3 students in each) in eight of the FabLab schools being surveyed. We did this to gain better insights into the types of implementations, types of student responses, and types of student gains that the survey was probing. In each interview setting, students were asked to fill out the questionnaire while reflecting on their answers. Interviewers probed the reflections whenever something of interest came up. Thus, while the interviews were heavily structured by the questionnaire, they were semi-structured in the sense that interviewers would follow leads before returning to the structure of the questionnaire. Students were selected for interview by their teachers, who were asked to identify those who had gained the most from work with digital fabrication. The present report focuses on the survey part of the work, and therefore the interviews are not directly reported. Here, we our sole use of the interviews is to divide schools into groups in order to compare different groups of schools.

3.6. Ordering of questionnaire themes

The survey was conducted as an online questionnaire consisting of 111 questions probing the students' abilities to use, master and understand digital technologies, to think and act innovatively (with technology) on societal challenges, and their relationship with the issues of digital data, hacking and reparation of technology. The students' personal background was investigated through questions relating to their socio-economic status and their dreams for the future. Abilities to use, master, and understand digital technologies were gauged through questions regarding technology in everyday use, the use of technology, and learning about technology in school. Finally, abilities to think and act innovatively (with technology) on societal challenges were measured through questions regarding design and creativity, while students' relationships with digital data and hacking were probed through their attitudes towards issues of privacy and ownership of data, towards tinkering with their devices, and towards hacking[1] as criminal activity or common practice.

Areas of interest	Number of questions
Personal background and plans for the future	9
Abilities to use, master and understand digital technologies	51
Abilities to think and act innovatively (with technology) on societal challenges	35
Relationship with digital data, hacking and reparation of technology	16

Table 1 - Relationship between areas of interests and the number of questions in the survey.

3.6.1. Types of questions

In the survey, four types of questions were used to investigate the various themes. Likert-type scale questions with a scale from one (strongly disagree) to six (strongly agree) were used to gain insight into the students' views and perspectives on technology and their activities within a concrete design process. In order to gauge self-perceived abilities within the areas of interest, an additional Likert-type scale was used with values ranging from one (I know nothing about it) to six (I could teach others about it). Evaluating the students' experience with digital fabrication technologies in schools was evaluated on a five-point Likert scale. Finally, open-ended questions and tasks were used in order to evaluate student abilities and mindsets. In this latter method, responses were coded for different categories of answers. The range of question types afforded opportunities for comparing self-perceived abilities with scores or categories on specific types of performance. For example, students were asked to rate their own knowledge of the AU Design Process Model, which could be compared to a question in which students were asked for ways to solve a concrete societal challenge.

It is important to note that on many items students were asked to evaluate themselves. This method is prone to various types of bias. One bias is that students are often uncertain of their own level of competence, and male students in particular tend to score their own IT skills higher than their female counterparts do (Bundsgaard, Rasmus Puck, & Petterson, 2014). Another is the so-called demand characteristic: Students' answers are often influenced by their wish to find the "right" answer, that is, to answer what they think the researchers or teachers want to hear. Students will often experience a survey as a test and will make attempts to do well in the given task.

[1] Note that hacking in this context should be understood not as a criminal activity (which is defined as cracking), but as a mindset of exploring and tinkering with the technology so as to come up with new and creative ideas for using the technology going beyond the originally intended use.

As stated, we used Likert-type scales with five or six possible answers. An uneven number of response possibilities is often recommended when using Likert-type scales to prevent respondents whose views genuinely lie in the middle of the scale being forced to answer to one side or the other and thus to be misrepresented in the data (Marsden & Wright, 2010). On the other hand, taking away the middle category gives even those respondents who are prone to satisficing (by choosing the option in the middle) in order to finish quickly an additional incentive to reflect on whether they are on one side of the middle or the other.

3.6.2. Translations and wording of questions

Parts of the survey had been translated into Danish from survey questions used in the FabLab@School project at Stanford University. While some questions were directly translatable, the interpretation of others in a Danish context posed problems. For example, concepts such as creativity and imagination can be interpreted differently in the two different contexts. The wording of the questionnaire was carefully selected with the goal of reducing the complexity of the language and having as little text as possible in order to speed up the reading process. At the same time, our aim was to be as precise and easy to understand as possible in order to secure valid data and to minimize fatigue and satisficing resulting from this fatigue. The questions and the questionnaire were tested on students within the age group on before deployment. During the testing, students were asked to read the questions aloud and discuss their answers, in order to reveal which words and wordings were difficult to understand and which questions were worded ambiguously.

The questionnaire opened with questions of age, gender, name, and school name. Demographic characteristics (number of books at home, expectations for the future) were placed at the end of the survey, as is frequently recommended (Marsden & Wright, 2010) in order not to cause respondents to feel intimidated or otherwise put off by questions about their background. Each section of questions was grouped by content, in order to facilitate respondents' cognitive processing (Marsden & Wright, 2010). The ordering of questions and themes had two main aims: first, to create a sense of a common thread running right through the questionnaire which would help the questions make sense to the respondents, and second, to make the students respond with their own uses and views on technology and design before revealing too much about our assumptions. The last aim was important to minimize demand characteristics, which might lead students to try to give us what they thought the correct answer.

3.7. Recruitment of schools

The schools within the project (the FabLab schools) were selected with help from the municipalities. The criteria for selection were (1) to have schools from all municipalities, (2) to have a diverse set of participating schools, and (3) to include only schools and classes that had worked with digital fabrication in education to a significant degree according to the municipalities. The local FabLab@School.dk coordinators from the municipalities informed the relevant teachers, whom we then contacted by email and phone.

With regard to the control group, criteria for inclusion were based on (1) whether the school had participated in the baseline survey, and (2) matches with project-schools. The selection was made so that a control school was found for each project school. The control school was to match the project school as closely as possible with regard to socioeconomic status, school size and the school's location in a rural, suburban, or urban setting. In each control school, we asked for a group of students in the same age range as in the corresponding project school. However, not all schools were organized alike, and we sometimes had to be flexible in order to get the data. We looked both at the individual matches and at the overall averages of the two groups. Socioeconomic status was represented by the expected average score on grade 9 national exams over a three-year period (2014-2016). This score is calculated from the socioeconomic status of each student in grade nine by the Danish Ministry of Education each year, and is publicly available.

School	Group	Grade	Number of students	Expected score (SES)
1	Control	8	32	7.1
2	Fablab	8	41	7.5
3	Control	7	17	6.7
4	Fablab	7	24	6.2
5	Control	6	20	7.1
6	Fablab	6	20	7.8
7	Control	7	51	7.4
8	Fablab	7	17	7.8
9	Control	7	22	5.3
10	Fablab	7,8	20	5.9
12	Fablab	8	41	7.6
13	Control	8	22	7.4
14	Fablab	8	20	7.4
15	Control	9	20	6.6
16	Fablab	9	46	6.5
17	Control	7	19	6.9
18	Fablab	6,7,8,9	17	6.4

Table 2: Participating schools. Control schools (odd numbers) are listed together with corresponding FabLab schools (even numbers). In the case of school 12, all potential control schools declined to participate in the survey, with the result that there is no school 11.

As seen in Table 2, we were able to find matches for all but one school. The total average and weighted average SES of schools within the two groups is shown in Table 3:

	Total number of students	Average SES	Weighted average SES
Fablab	246	7.0	7.0
Control	203	6.8	6.9

Table 3: Total number of students in the FabLab and control groups, and comparison of their Socio-economic status' as represented by average expected scores on national exams.

While the weighted average SES is not identical for the two groups, the difference is very small. Thus, we do not expect any difference in responses to be due to a difference in the socio-economic status of the two groups.

3.7.1. Grade level of the respondents

In the following, we compare the grade level of the FabLab and control groups.

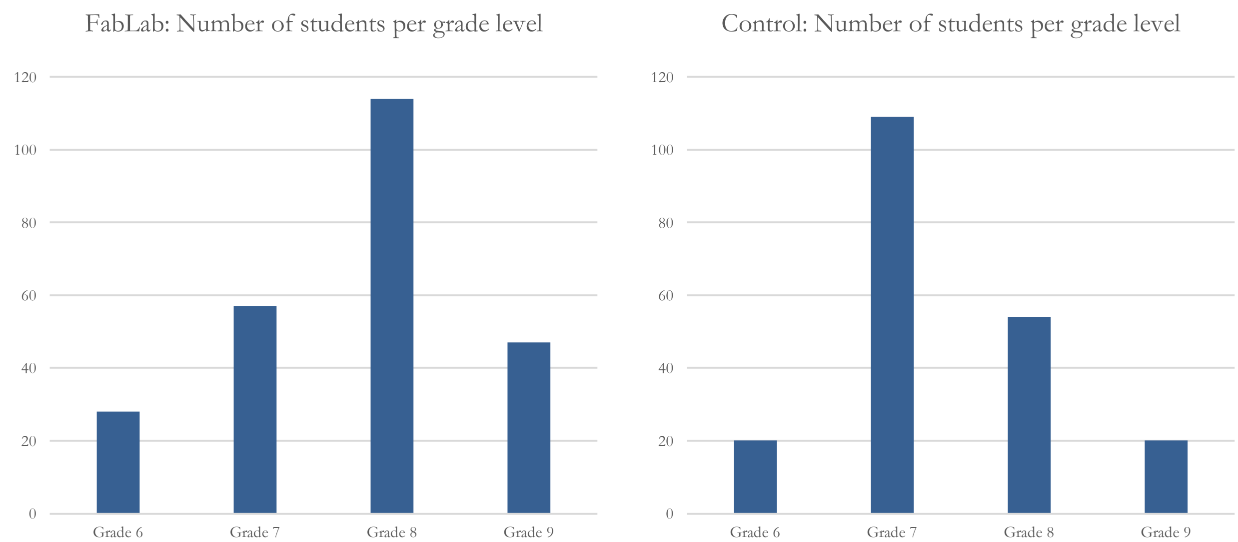

Figure 1: Number of students at each grade level in the FabLab and control groups respectively.

As seen in Figure 1, students in the FabLab group were older on average than the students in the control group. There were two main reasons for this difference. The first was, that in school 16 (FabLab), the entire group of grade-nine students had participated equally in the FabLab activities and we therefore included all students from this grade, which gave us 46 responses. In the corresponding control school, however, there was only one class in grade nine, which gave us 20 responses. Furthermore, we failed to find a willing control school that could match school 12. Thus, the 41 responses for grade eight students from this school are unmatched in the control group. Number of students in each grade level in the 2014 survey is listed in Figure 2.

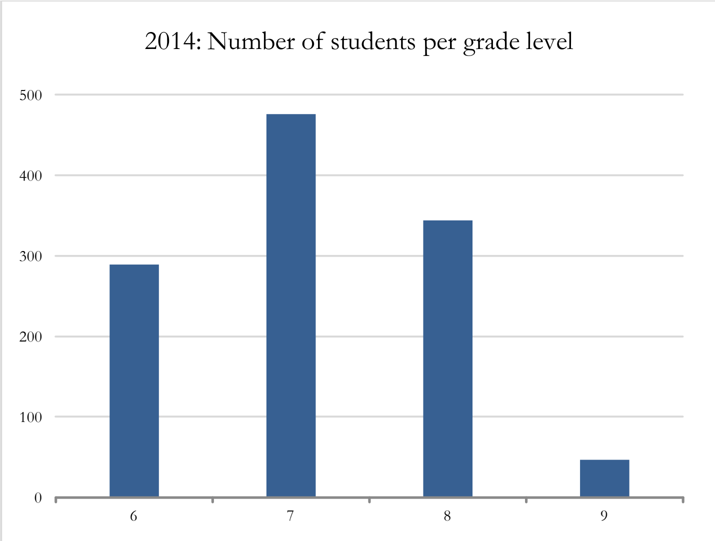

Figure 2: Number of students at each grade level in the 2014 baseline survey.

The students in the 2014 survey (see Figure 2) were on average younger than those in the 2016 survey. We did not try to control the grade level of participating classes in the 2016 survey, since the most important selection criterion in the FabLab group was to survey the classes that had worked most with digital fabrication technologies. The most important selection criterion for the control schools was to match FabLab schools as well as possible.

3.8. Data treatment

The data was downloaded from SurveyXact as a Microsoft Excel file. The original data file contained 551 entries. Responses that did not fit the criteria mentioned below were deleted, and the final number of responses in the FabLab and control datasets combined ended up at 449.

3.8.1. Blanks

If someone started a questionnaire without filling in anything at all, an entry was created. Such a case was counted as a blank. It is very probable that we created most of these ourselves, since every time we tested whether the server was running, a blank entry was created. 72 blanks were deleted from the dataset.

3.8.2. Duplicate entries

Due to technical problems, several students needed to start over on the survey, thus creating duplicate entries. In each case, the entry with the most answers was kept in the data set, and the others were deleted. Four records of duplicate entries were deleted.

3.8.3. Age range

In this survey we were researching 11-15 year olds, and therefore any entries outside this range were deleted. Nine responses were deleted because the respondents had put something unrelated to age in the age field, or had stated an age which was out of bounds.

3.8.4. Completion

It was decided to only keep only responses in which the respondent had completed the entire questionnaire. For this reason, 17 entries with uncompleted questionnaires were deleted.

3.1. Notes on statistical analysis

All statistical analysis was carried out in R (RStudio Team, 2016). As is customary, we applied a p-value of 0.05 in our statistical tests. In other words, whenever there is a less than five percent chance that an effect could have arisen randomly, we accepted this effect as significant. However, as has been pointed out (Field, Miles, & Field, 2012), when 100 different parameters are tested with an accepted p-value of 0.05, five of these will show significant effect by chance even if there are no effects (corresponding to the five percent chance of random effects). This is known as familywise error. Since we often included more than one question in a family of questions, we have used the Holm-Bonferroni correction to adjust p-values within batteries of questions. The Holm-Bonferroni method is a relatively conservative way of dealing with family-wise errors, and we do run the risk of getting false negatives – that is of reporting no effects, when in reality there were effects (Gelman & Hill, 2007). Because of this risk, in some cases we will discuss the descriptive differences but add that the effects were not significant.

As explained later, in most batteries of questions, it could be argued, that schools should be treated as random effects. Since we only had surveyed students taught by one teacher in each school, the effect of schools included the effect of the teachers. That is, if we wanted to find effects that were independent of the difference made by teachers and schools, we needed to take the effect of schools into account by using them as random effects in our models. However, since we did not have the opportunity to control schools' choices of technologies or implementations, such analysis rarely rendered any effects significant. The effect of teachers' differing implementations of different technologies in many cases did not yield results that could be generalized to all teachers in all schools in the area. In some cases below, we discuss results both with and without treating schools as random effects.

4. Digital fabrication in schools

In the FabLab@School.dk project, students worked with a range of different digital fabrication technologies. In this section we describe students' responses to questions regarding their use of such technologies, their knowledge of them, and whether or not, they had learned to use the selected technologies in school. We asked these questions in order to gauge students' "abilities to use, master and understand digital technologies."

4.1. Exposure to digital fabrication technologies

In the questionnaire students were asked which technologies they had worked with, and whether they had used them to work with their own ideas or whether they had followed a set of instructions. Because the FabLab@School.dk project was centered on introducing FabLab technologies to students in schools, we expected students in the FabLab group to have worked with more technologies than students in the control group.

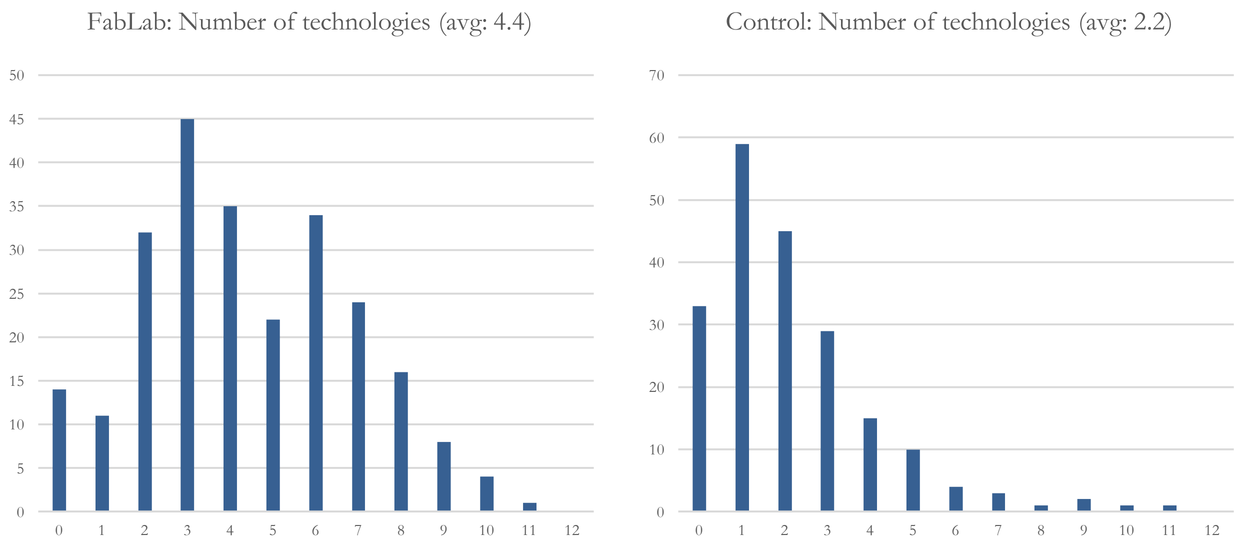

Figure 3: Average number of technologies used by FabLab and Control groups respectively. Answers in the category "other FabLab technologies" were excluded from these charts (as explained in text).

As seen in Figure 3, FabLab group students had on average been exposed to more digital fabrication technologies (4.4 technologies per student on average), than students in the control group (Average: 2.2). We were, however, surprised, both by how many students from the control group had worked with digital fabrication technologies and by the broad range of digital fabrication technologies the control group students had worked with (see below).

4.2. Exposure to different kinds of digital fabrication technologies

Figure 4 and Figure 5 show the percentages of students in the FabLab group that had been exposed to each selected technology.

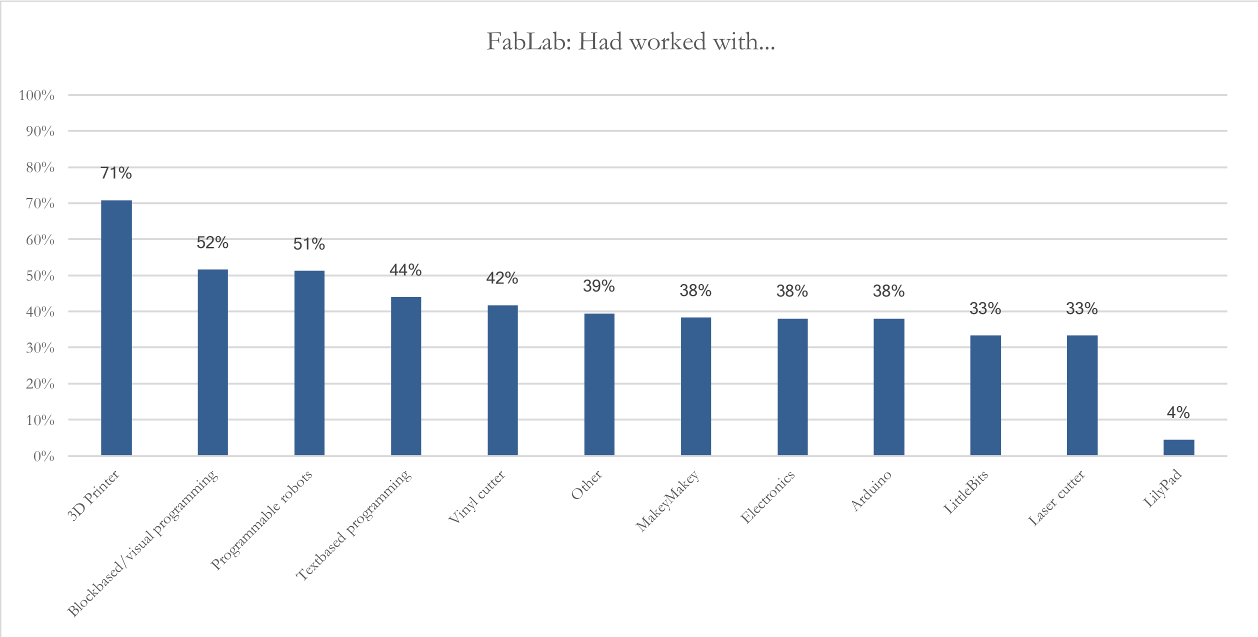

Figure 4: Percentage of students from the FabLab group, who reported to have used the listed technologies.

As seen in Figure 4, seventy-one percent of the students in the FabLab group reported that they had worked with 3D printers. At the other end of the scale, fewer than five percent of the students reported, that they had used the LilyPad Arduino. In the literature surrounding the development of the LilyPad it is often claimed that because it is meant to be used with textiles, the LilyPad appeals to girls more than other technologies (Buechley, Eisenberg, Catchen, & Crockett, 2008). Thus it is perhaps surprising that more schools had not chosen to introduce the LilyPad in their FabLab activities in order to engage the girls. On the spectrum between the LilyPad and the 3D printers, was a range of technologies which between 33 and 52 percent of the students reported having worked with. These technologies included Blockbased/visual programming (52 percent), Programmable robots (51 percent), Textbased programming (44 percent), and vinyl cutters (42 percent). Further, more than one third of the students from FabLab schools had worked with MakeyMakey (38 percent), Electronics (38 percent), Arduino (38 percent), LittleBits (33,3 percent), and Laser cutters (33,3 percent). Only schools that had worked with some digital fabrication technology or technologies were selected for the survey. Among these schools, however, there was a large variation in the technologies, each school was using (see section 4.4).

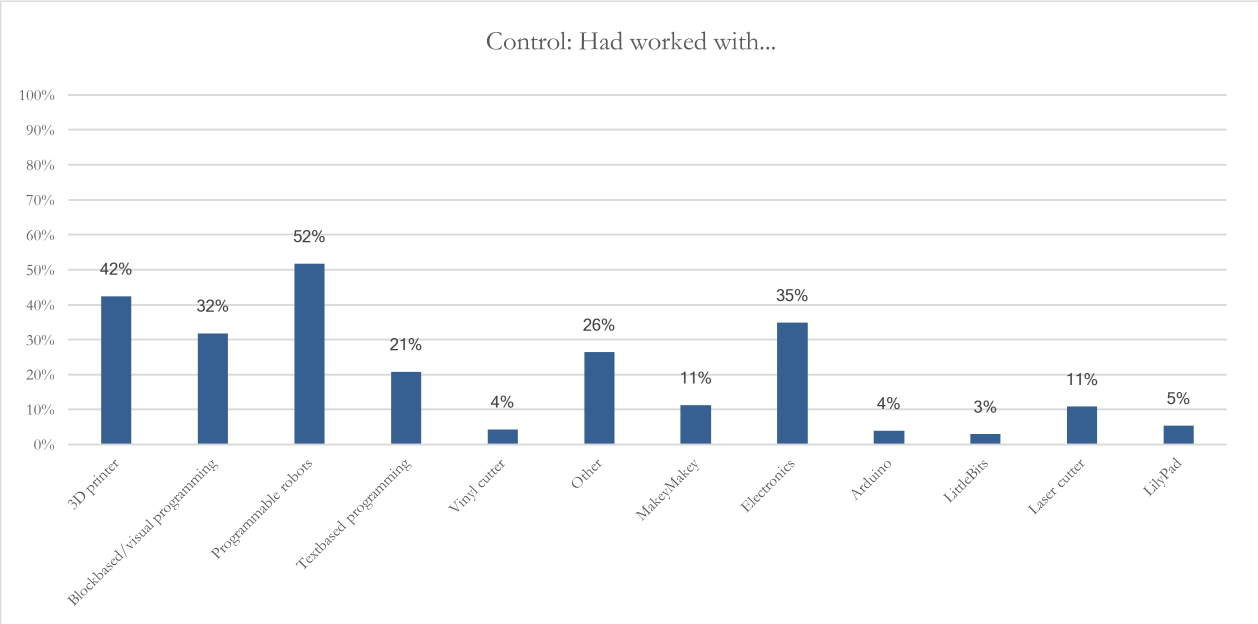

Figure 5: Percentage of students from the control group, who reported to have used the listed technologies.

As depicted in Figure 5, students from the control group reported working with a range of technologies, among which the most common were programmable robots (52 percent), 3D printers (42 percent), and electronics (35 percent). Thirty-two percent reported that they had used block-based or visual programming, while 21 percent had worked with text-based programming. Some students reported that they had worked with MakeyMakey (11 percent) and laser cutter (11 percent), while few students had worked with LilyPad (5 percent), vinyl cutter (4 percent), Arduino (4 percent), and LittleBits (3 percent). Twenty-six percent reported that they had worked with other digital fabrication technologies. When these students were asked to state which other digital fabrication technologies they had worked with, however, they all mentioned either technologies that did not fit our definition (e.g. iPads, computing in general) or technologies that were already included (e.g. LEGO Mindstorms).

Comparison of the charts reveals that a higher percentage of students from the FabLab group than the control group had worked with most technologies. The only exceptions were programmable robots and LilyPads. However, many students from the control group claimed to have worked with digital fabrication technologies. For example, more than 40 percent of students in the control group claimed to have used a 3D printer. Two schools in particular seemed to have worked with 3D printers: only six out of 51 students from school seven and four out of 17 students from school three reported that they had never used a 3D printer. That so many of the students from our control group had worked with digital fabrication technologies highlights the difficulties of working quantitatively with real schools in real-world settings: we had no authority to demand that control schools did not use 3D printers or other digital fabrication tools, and thus we did not compare the FabLab group to a group of students that had not been working with digital fabrication technologies. Therefore, effects sizes measured by comparing FabLab to control schools, were lessened by the control groups' exposure to digital fabrication.

There were visible differences between FabLab (Figure 4) and control group (Figure 5) students' self-reported work with all the listed technologies except LilyPads, robots, and electronics. However, when testing whether or not these differences between the control group and the FabLab group are statistically significant, the schools, students came from, should be taken into account. Since different teachers in different schools teach in different ways to different groups of students, any comparison of effects on groups of students needs to check, that differences between effects on different groups of students are not only created because of differences between schools. In statistical jargon, this means that the school, students come from, should be treated as a so-called random variable. That is, if we wanted to show an effect that was true irrespective of which school digital fabrication technologies were introduced to, we would have to factor out the importance of school, teacher, and implementation. Treating school as a random variable did not allow us to conclude, that the differences, which we had observed in the charts, were statistically significant – with two exceptions: students within the FabLab project had used both Arduinos and vinyl cutters to a statistically significant greater extent than those in the control group. As already noted, we were not able to choose, which technologies each school implemented in either FabLab or control groups. In subsequent sections of the report, we treat the differences between groups of schools in more depth.

4.3. Comparing groups of schools

As described above, we found large variations between schools within the FabLab group. This variation meant, that comparisons between the FabLab group, the control group, and the group from the 2014 survey did not produce the insights, we had expected. Below, we have explored the variation within the FabLab group by dividing this group into groups of archetypical categories. As described in section 3.5, we conducted interviews with eleven groups of students in eight FabLab schools. In each school, teachers were asked to identify and select two or more students who had benefitted the most from working with digital fabrication. Thus in these eight schools we gained qualitative insights into the highest outcomes from the teaching done there. In a subsequent analysis of student interviews, the responses were clustered into four types of schools using an affinity diagramming approach (Beyer & Holtzblatt, 1999). In the end, schools were placed in four archetypical categories based on students' recollection of projects with digital fabrication within four different perspectives: (1) the number of technologies applied from the teacher's and school's repertoire, (2) the degree to which the work with digital fabrication technologies had been framed as explorative design processes, (3) the degree to which the students had worked systematically with complex problem-solving, and (4) the degree to which the work with digital fabrication technologies was seen as an integrated part of school work in general. We then used the four archetypical categories to analyze the survey data in order to look for trends within the FabLab group. The four archetypes are characterized in Table 4. Each of the groups have been given a color in order for the purpose of clarity.

	Use of digital materials	Combination of digital fabrication and design processes	Systematic work with complex problem solving	Digital fabrication and design integration in school curriculum
Group 1: Green	Used a large repertoire of digital technologies	Used design process models to scaffold digital fabrication processes	Systematically worked with complex problem solving through several projects with digital fabrication	High degree of integration between digital fabrication, design processes and other school activities
Group 2: Orange	Used a large repertoire of digital technologies	Used design process models to scaffold digital fabrication processes	Worked with a technology focus or with tame school problems.	Had to some degree integrated digital fabrication and design with other school activities.
Group 3: Purple	Used a large or medium-sized repertoire of digital technologies	To small or some degree used design process models to scaffold digital fabrication processes	Primarily worked with digital fabrication technologies in confined school tasks without relation to problem solving.	Had to small or some degree integrated digital fabrication and design with other school activities.
Group 4: Red	Used a small repertoire of digital technologies	To some or small degree used design process models to scaffold digital fabrication processes	Primarily worked with digital fabrication technologies in confined school tasks without relation to problem solving.	Had to small or some degree integrated digital fabrication and design with other school activities.

Table 4: Groups of schools created on a basis of interviews with students from the included schools.

Group 1 consisted of students from one school in which interviews indicated, that students had a high degree of ownership for the FabLab projects, that they rated the importance of the process highly, and that they saw a connection between design and technology as a process directed towards societal development and change. These students were able to reflect on how design and technology were changing the way we live, and they saw connections between what they did in the FabLab and society, their identity, and their own lives. Group 1's expected average result on national exams (as a socioeconomic reference) was 7.5, which was well above the average of 7.0 of the FabLab group.

The students who were interviewed from group 2 were very tech-savvy. They worked with the technologies outside of school as well as in school. They were able to creatively think with different materials. They had a high self-confidence with regards to technology, and they had a high degree of ownership for the FabLab projects. They were mainly concerned with the technology and with what they could use the technology to produce in the fabrication phase of designing. They were less concerned with the design process as an approach to working with technology and complex problems. They engaged with tinkering, experimenting and iterating with the technologies. Students from group 2 had an expected average examination result of 7.8, which was the highest in the FabLab group.

The students interviewed from group 3 were a bit less uniform. Some of them had a basal knowledge of digital fabrication while others had a low knowledge of the included technologies. Some students stated, that they had been introduced to the technologies, but that they had not experienced the chance to actually work with them. Others responded that they had tried many different technologies, but that the technologies were always changing, in line with the activities, which they described as introductory activities such as creating keychains, stickers, and driving a Sphero robot on a track. Most of these students saw some kind of potential in the technologies, but they lacked interest, knowledge, or reasons to identify themselves with digital fabrication in order to engage with the projects. Some students did not understand, how these technologies were relevant to personal lives or their future careers. The boys in this group seemed to be motivated by performing well in school, as the driver for their engagement in the FabLab@School projects. Most of the students in this group had some knowledge of design processes, but lacked experience or motivation of how this could be applied in other projects or subjects. The schools in this group recruited students with an average expected exam score of 7.5, which was at the same level as group 1 and which was well above the total average in the FabLab group.

Students in group 4 in general had some basal knowledge of a few digital fabrication technologies. Some had worked with either LittleBits or Arduino, others had seen how the laser cutter or 3D printer worked and perhaps printed a logo sticker or a key-chain. They were not self-confident with regards to their knowledge of the technologies. They had worked with few, stand-alone projects, but they generally found it difficult to remember, what they had done. In general, they lacked interest in FabLab and found it somewhat boring. They described work with digital fabrication in school as too much talk by the teacher and only few student-driven projects. The students in this group lacked a vocabulary for talking about, what they had done both technologically and with regards to the design process. Students from this group on average had an expected examination average of 6.1. This was low compared to the FabLab average of 7.0 and very low compared to the schools in other archetypical categories. In the following sections, the four groups of FabLab schools described in Table 4 will be used to look for trends in the responses by students from each group.

4.4. Exposure to technology in group comparisons

One noticeable difference between the groups was the average amount of different types of technologies, they had used. There were of course several different strategies for using digital fabrication technologies: in one of the schools in group three, for example, new technologies were introduced frequently but more or less randomly according to the students interviewed. Other schools may have focused on using a few technologies to achieve an understanding of these in more depth, but it seems probable that the number of technologies to some degree reflected the emphasis placed on FabLab@School. Figure 6 depicts the average number of technologies used by students in each school group.

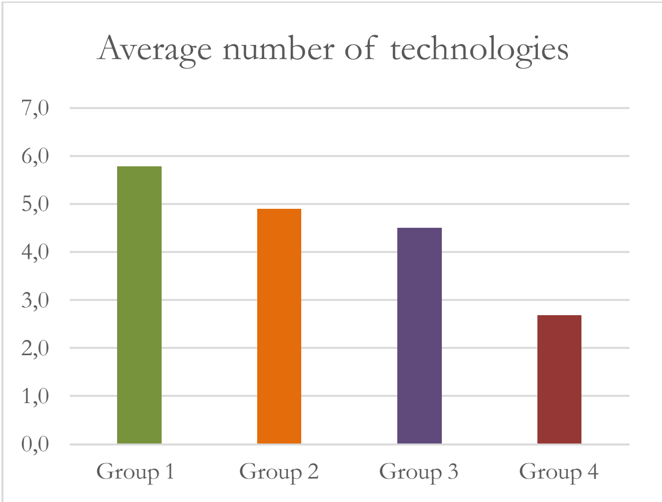

Figure 6: Number of technologies used in the different school groups.

As seen on Figure 6, there were large differences between groups one (5.8 technologies on average) and four (avg: 2.8). This is consistent with the group four students' descriptions of relatively sporadic FabLab-projects as compared to group one's consistent focus on FabLab throughout the entire FabLab@School.dk project period. Students from both group two and group three had used between four and five different technologies on average. However, the students interviewed from group two had talked about doing interesting projects with the technologies, whereas those from group three had talked about being introduced to technologies more at random. In the next section, this difference will be investigated through survey answers.

Within groups of schools, there were great variations in the number of technologies, each student reported using. Figure 7 shows the number of students from Group 1, who claimed to have worked with each possible number of technologies.

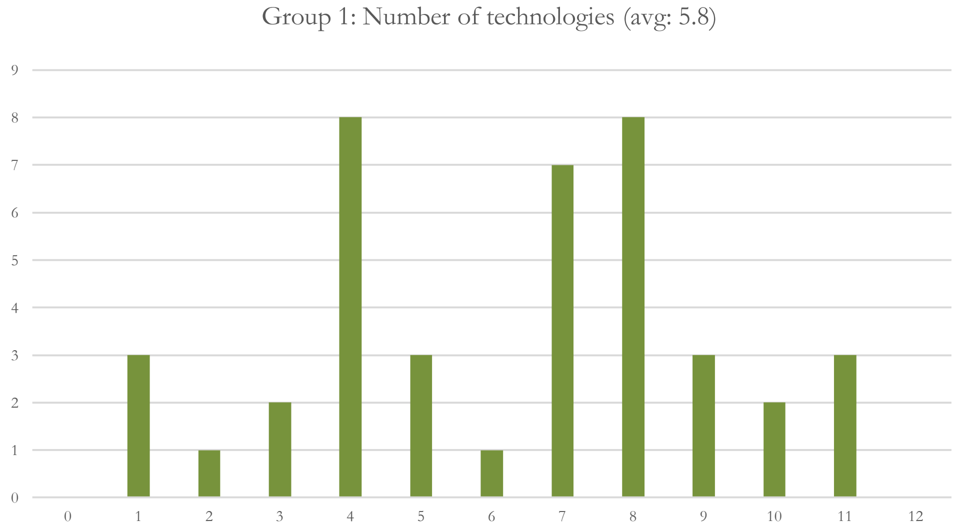

Figure 7: Number students in Group 1 that claimed to have used each possible number of technologies.

Group 1 consisted of only one school, and even within this one school, the number of used technologies varied greatly. While some of this variation may to be due to students not reporting correctly and some of it may be due to students having used technologies outside of school, the variation could also point to a project-oriented approach in which digital technologies were tailored to the individual project.

4.5. Approaches to working with digital fabrication technologies

It is often emphasized in the FabLab@School.dk project (see, e.g., the project focus in section 3) that digital fabrication technologies should be introduced to schools with the purpose of giving the students a chance to be creative with them. Therefore, our hypothesis was that schools taking part in the FabLab@School.dk project would use digital fabrication technologies more frequently to work with students' own ideas. In the survey we therefore asked students to rate their experiences with maker technologies according to whether they had been following instructions or developing their own ideas. Responses are summarized in Figure 8 and Figure 9.

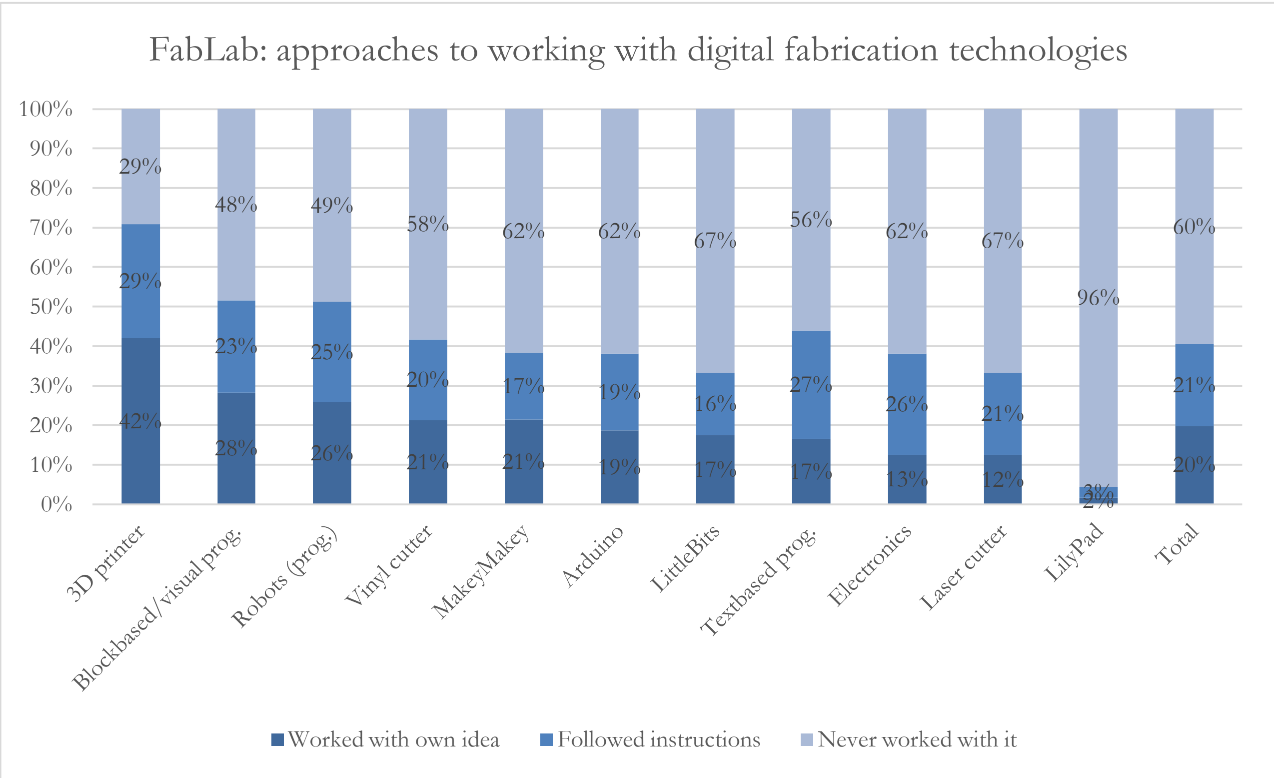

Figure 8: Approaches to working with the technologies in the FabLab group. Students' responses to questions of whether they had used the technologies to work on their own projects, or whether that had followed instructions. Ordered by "Worked with own idea". Last column displays the overall percentages.

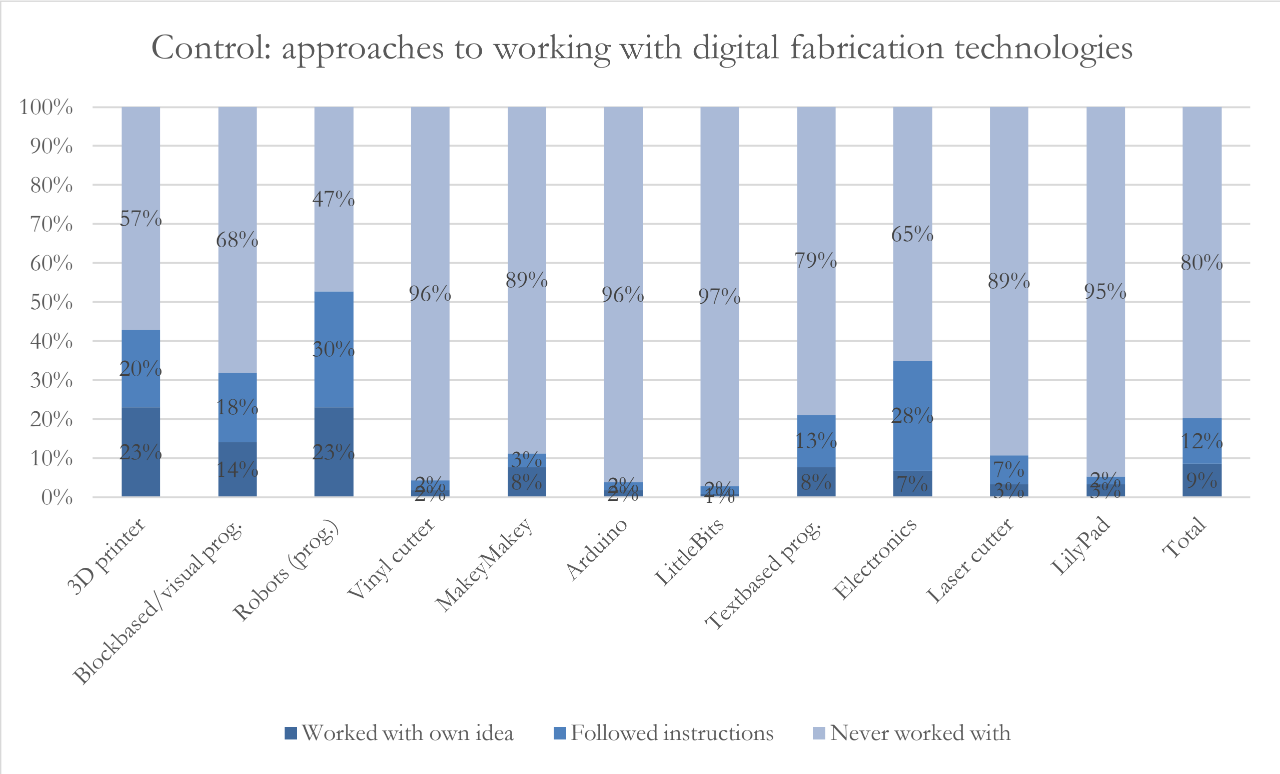

Figure 9: Approaches to working with the technologies in the control group. Students' responses to questions of whether they had used the technologies to work on their own projects, or whether that had followed instructions. Ordered to match the ordering of the corresponding chart for the FabLab group. Last column displays the overall percentages.

As seen in Figure 8 and Figure 9, there were visible differences in the approaches between FabLab and control groups on some technologies. For example, in the control group seven percent of the students reported that they had used electronics and soldering to work on their own ideas, while 28 percent reported that they had used electronics while following instructions. This amounted to a ratio of 1:4. In the FabLab group, 13 percent had worked with their own ideas and 26 percent had followed instructions, which amounted to the ratio 1:2. Such differences were, however, not statistically significant. Furthermore, these differences in approach for each technology were scattered. Another way to look at the data in Figure 9 and Figure 9 was by looking at the total number of technologies each student claimed to have used for working with their own ideas and for following instructions respectively. In particular the average number of technologies used for working with their own ideas by students in each group would be valuable in order to gauge their experience with problem-solving. These are shown in Figure 10.

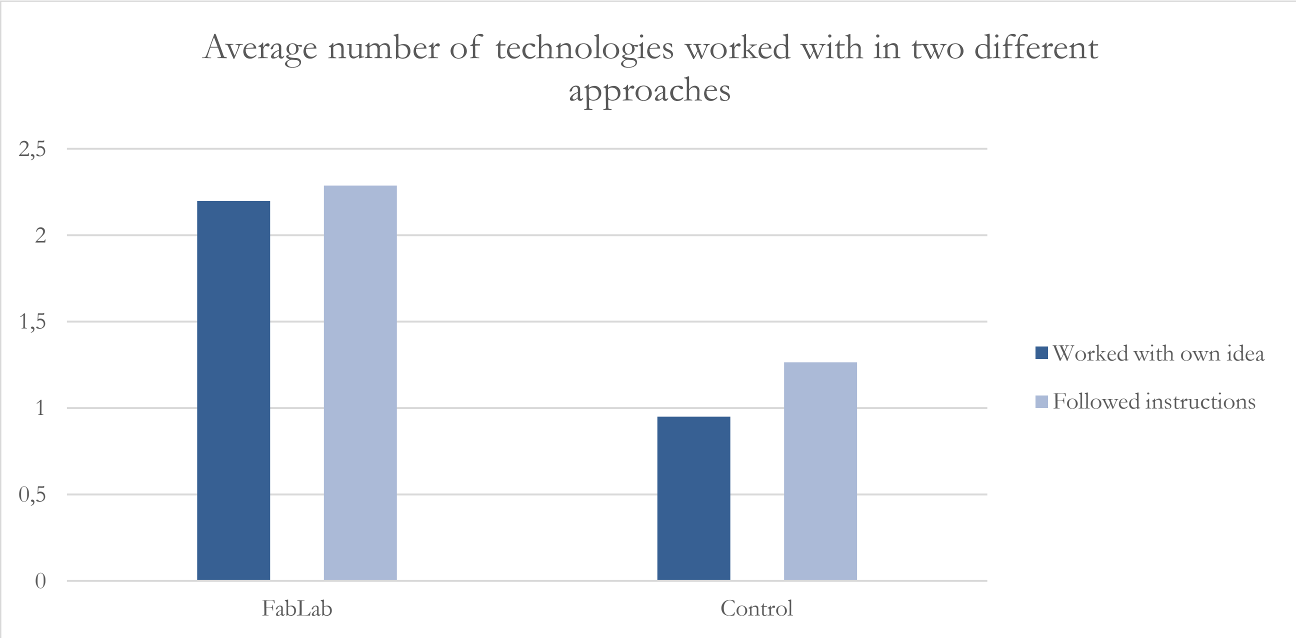

Figure 10: Average number of technologies used in the FabLab and control groups with the two different approaches of either following instructions or working with own ideas.

As depicted in Figure 10, the FabLab group students on average claimed they had been using approximately the same number of the listed technologies to work with their own ideas (2.4 technologies on average) and in following instructions (2.5 technologies on average). On average, control group students reported that they had used 1.0 technologies for working with their own idea and 1.3 technologies in following instructions. There were, however, large variations between students within both the FabLab and the control groups. These variations are explored further in Figure 11 and Figure 12.

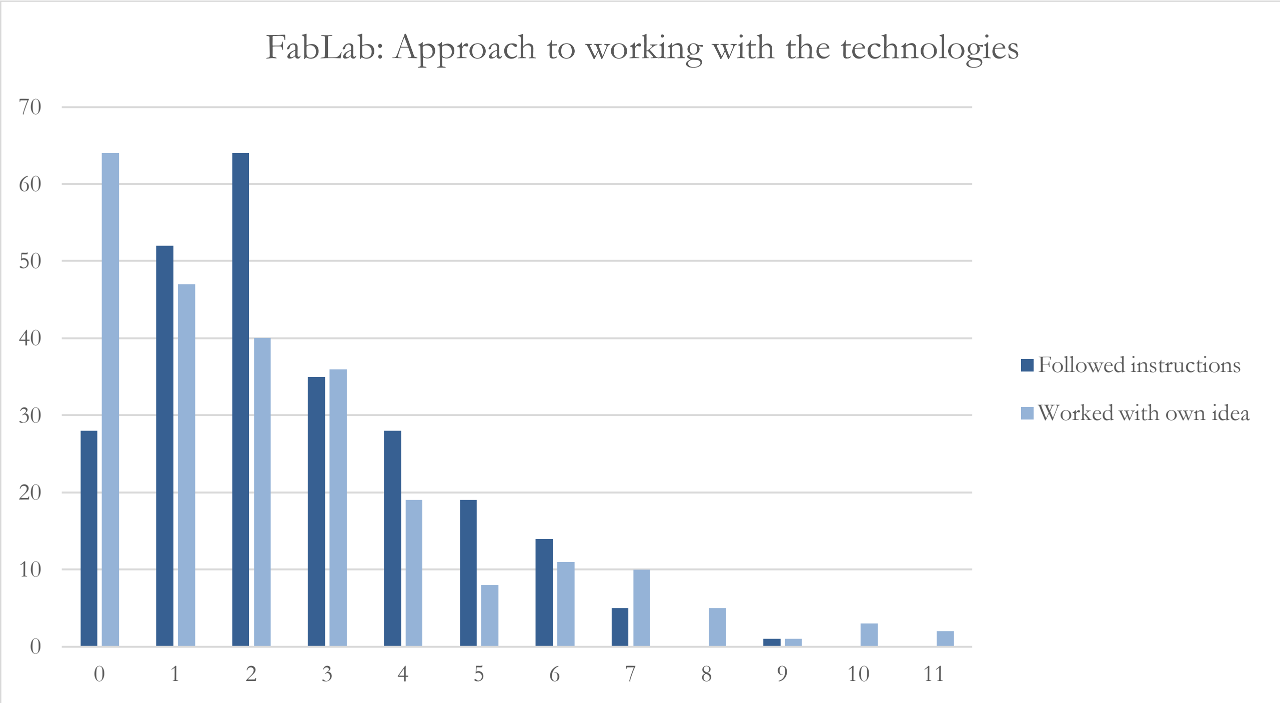

Figure 11: Average number of technologies used in the FabLab group with the two different approaches of either following instructions or working with own ideas.

As shown in Figure 11, Sixty-four students from the FabLab group (26 percent) claimed that they had never used the listed technologies to work with their own ideas, whereas 40 students (16 percent) had used five or more technologies for working with their own ideas. Thus, there were large variations within the FabLab group, and a fourth of the students reported, that they had never tried to use a digital fabrication technology to work on their own idea.

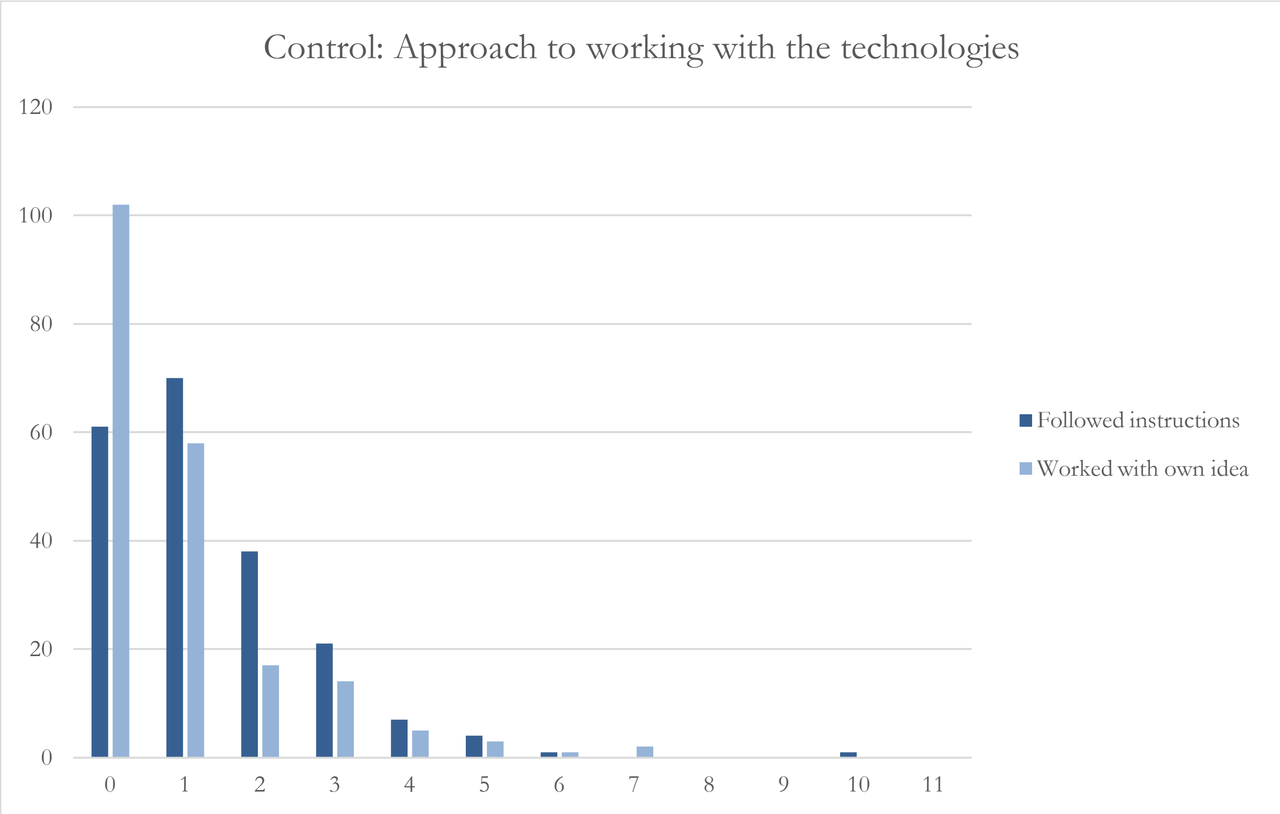

Figure 12: Average number of technologies used in the FabLab group with the two different approaches of either following instructions or working with own ideas.

As shown in Figure 12, 102 students (50 percent) in the control group claimed they had not used any of the listed technologies to work on their own ideas and only six students (3 percent) had used five or more of the technologies for this. Thus, while there was also some variation in the control group, this variation was centred around whether or not these students had been working with any digital fabrication technologies. The ratios between approaches were different in the two groups: in 48 percent of the instances in which FabLab students reported using one of the listed technologies, they reported that they had done so while working with their own ideas. This was true for 41 percent of the control group students. In conclusion, then, the FabLab students had both experienced a higher ratio of working with their own ideas and had been working with their own ideas across a much wider range of technologies.

4.5.1. Differences between schools within the FabLab group

As was the case with the total number of technologies used, there was a large variation between schools with regards to whether they used technologies by working with students' own ideas or in following instructions. In Figure 13 we have depicted approaches for each technology between groups one to four.

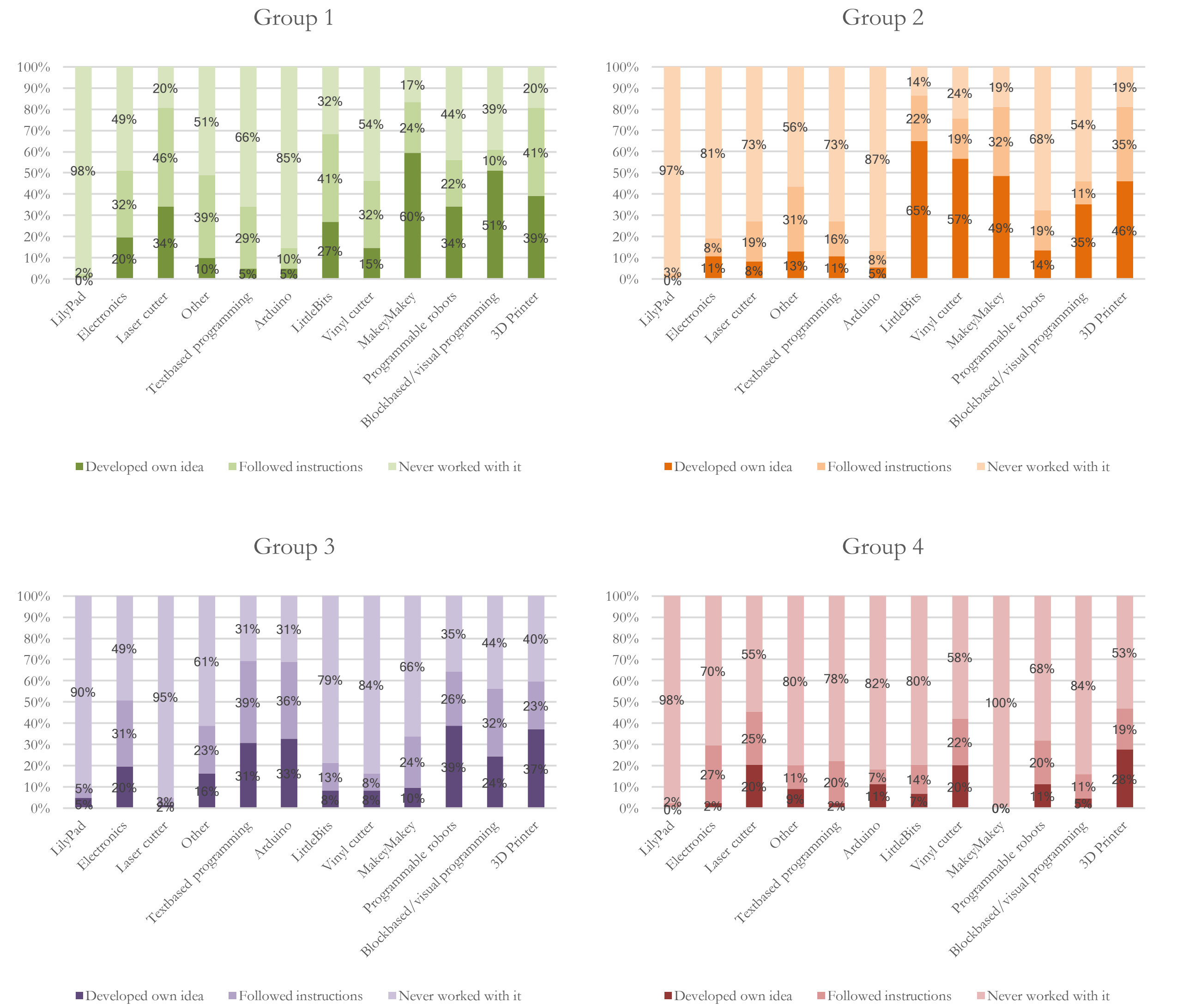

Figure 13: Approaches to working with digital fabrication technologies in the four groups. Expressed as percentages of students in a group, who claimed using the technology in a given approach.

Figure 13 shows variation between the ways in which students from different groups of schools had worked with each technology. Because teachers from each school could choose how to use the technologies, there were large variations among schools in terms of which of two teaching approaches they had used. For example, of the students in groups one, two, three, and four, 83, 81, 34, and zero percent respectively reported using the MakeyMakey. Out of these students, 71 percent from the group 1 claimed using the MakeyMakey for working on their own ideas, whereas the same was true for 60 percent of the students from group 2 and 29 percent of the students from group 3. The use of LittleBits appeared to reverse this trend: Of the 68 percent of students in group 1 who claimed using LittleBits, 39 percent claimed using it to work on their own ideas. The same was true for 75, 38, and 33 percent of the students in groups 2, 3, and 4 respectively. The trend in regard to uses of LittleBits to a degree contradicts the corresponding trend in using MakeyMakey. Thus, there were large variations between school groups in regard to which technologies teachers chose to implement in either of the two approaches. Figure 15 displays the number of students in each group, who claimed using a given number of technologies for working with own ideas and in following instructions respectively.

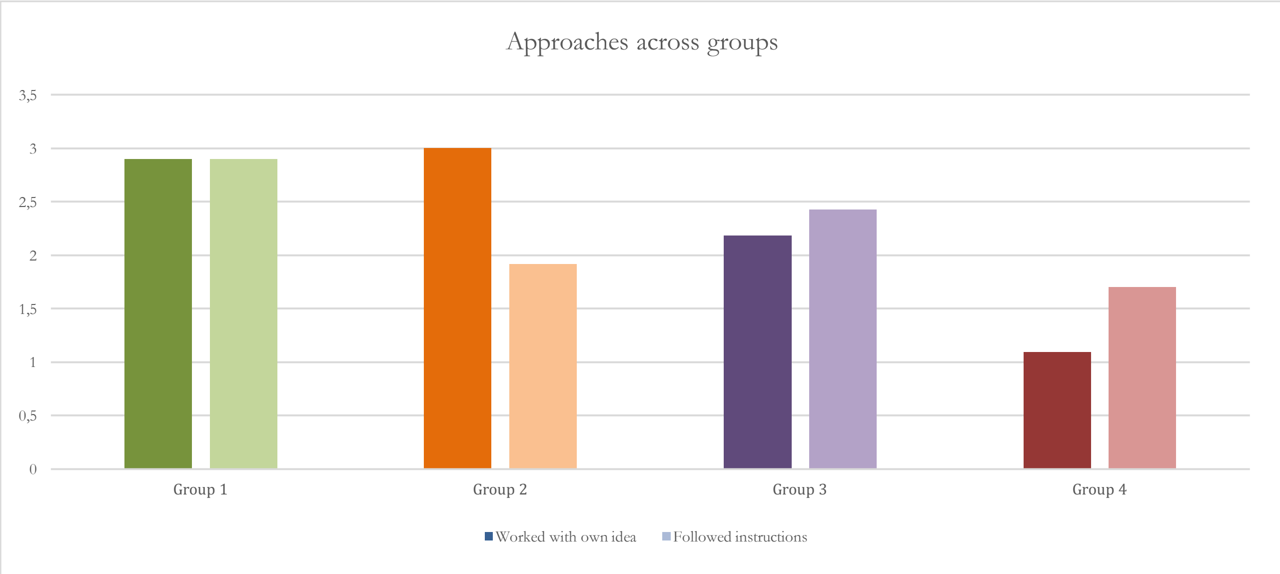

Figure 14: Number of technologies used to work with own ideas (darker bars) and in following instructions (lighter bars) across groups.

As shown in Figure 14, there were large differences between the approaches of some of the groups. In group two, more technologies had according to students' responses been used to work with students' own ideas than had been used in following instructions (61 percent). In groups one and three, approximately equal number of technologies had been used in the two approaches (50 percent and 47 percent respectively), whereas in group 4, students claimed they had used more technologies to follow instructions than they had to work with their own ideas (39 percent). Since this pattern to a certain extent follows the number of technologies used, it could be that the more technologies are used by students in a school, the more they will be allowed to use them for their own projects. However, in this trend, group two stood out. Here, students answered that almost two-thirds of the technologies they had used, had been used for working on their own ideas. Whether teachers teach by letting students follow instructions or by letting them work creatively on their own ideas is obviously a matter of teacher style, student group, and parents' expectations, among other influential factors. Thus, while there was a trend towards working more with own ideas in the groups who had worked with a larger number of technologies, this trend needs further investigation.

In Figure 15 we explore the extent to which there were variations between students in regard to the number of technologies they had worked with in the two approaches.

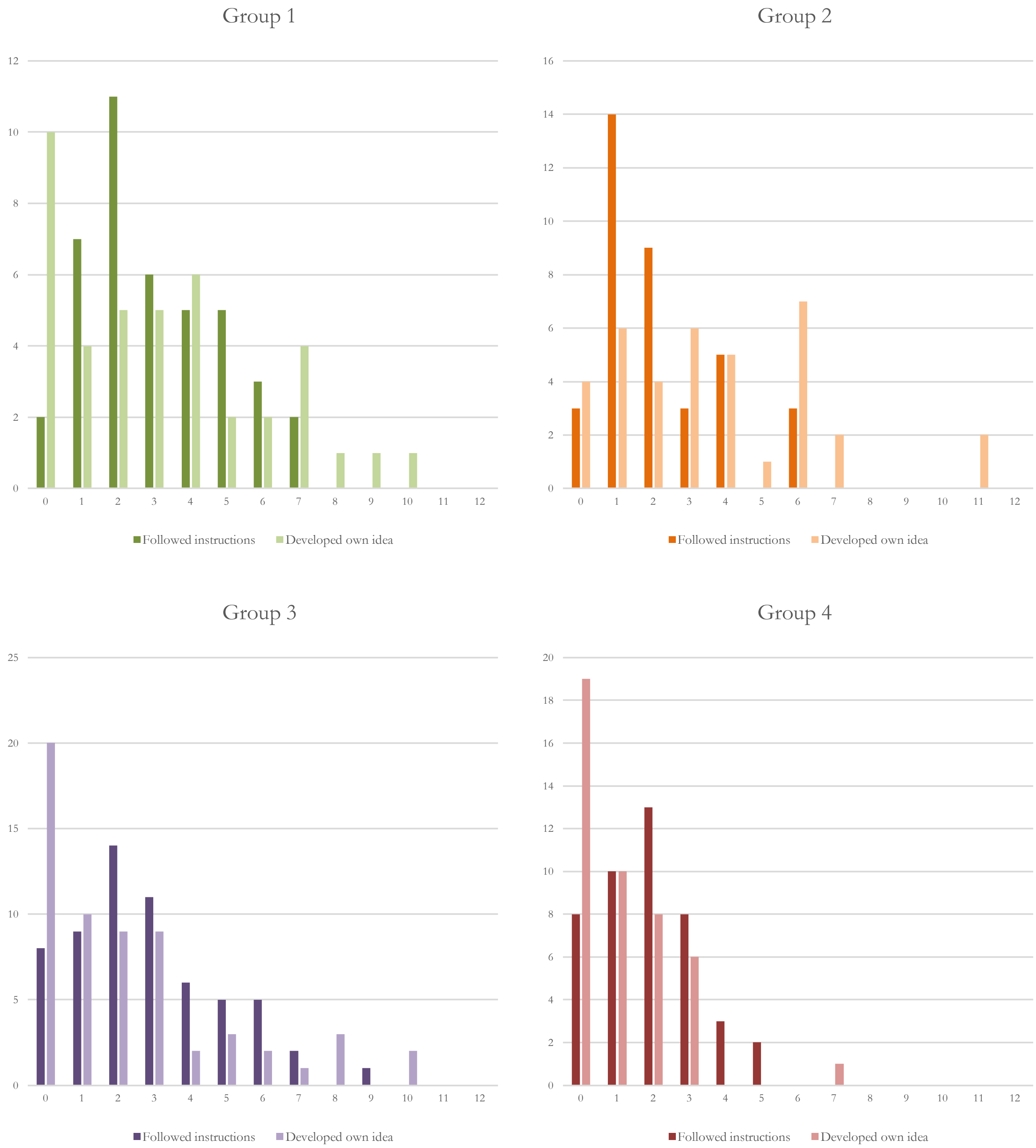

Figure 15: Frequency of students who had worked with a given number of technologies by following instructions and developing own ideas in groups one, two, three, and four.

As shown in Figure 15, students' responses with regards to how many technologies they had used to work with their own ideas did not follow a normal distribution (bell curve) for groups 1 and 2. Rather, there were large differences between students within the same group. In group 2, two outliers claimed to have used all 11 technologies to work on their own ideas. These outliers have a large impact on the average for group 2 (37 in total). Without the two outliers, students from group 2 had on average used

2.4 technologies to work with their own ideas, which follows the trend of a correlation between the total number of technologies used and the number of technologies used to work on own project. From their responses to other items in the questionnaire, the two outliers did, however, seem to take the survey seriously, and so we do not propose, that they should be removed. Rather, we wish to use the calculation to point to the possibility, that when teachers become more experienced in working with digital fabrication technologies, their tendency to let students work with own ideas increases. In group 1, ten students responded, that they had not used any of the technologies to work with own ideas, whereas nine students had used six or more technologies to work with own ideas, according to their responses. Since these students all came from the same school (there was only one school in group 1), the variation could suggest, that this school worked with digital fabrication technologies in a project-based approach, in which there was a great differentiation between the groups with respect to how they used the technologies. Overall, the conclusion is, that even within schools and groups of schools, there were great variations in student responses in regard to the number of technologies used to work with own ideas.

4.6. Knowledge of the technologies

In both the 2014 and the 2016 surveys, students were asked to rate their knowledge of technologies on a scale of 1 (I know nothing about it) to 6 (I could teach others about it). In Figure 16, Figure 17, and Figure 18 below, it can be seen that the FabLab group students on average rated themselves higher than both the 2014 group and the control group.

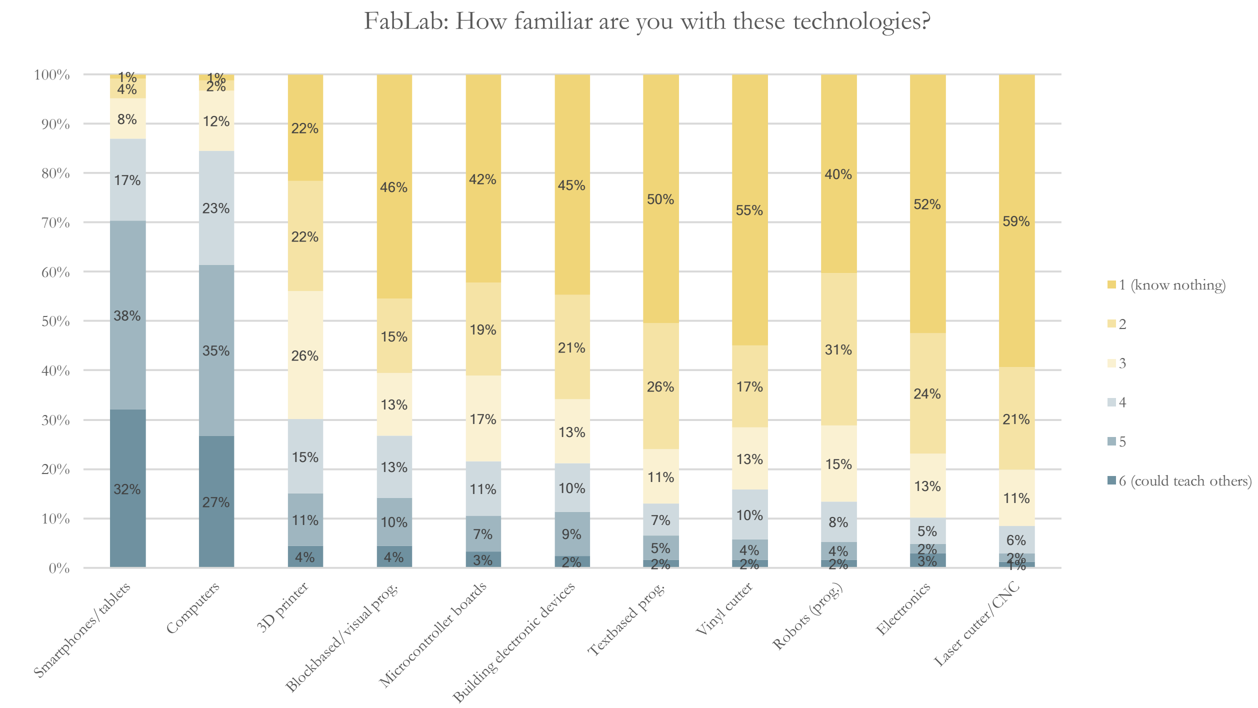

Figure 16: FabLab group students' responses on self-perceived knowledge of technologies. Ordered by the sum of percentages of students in categories 5 and 6.

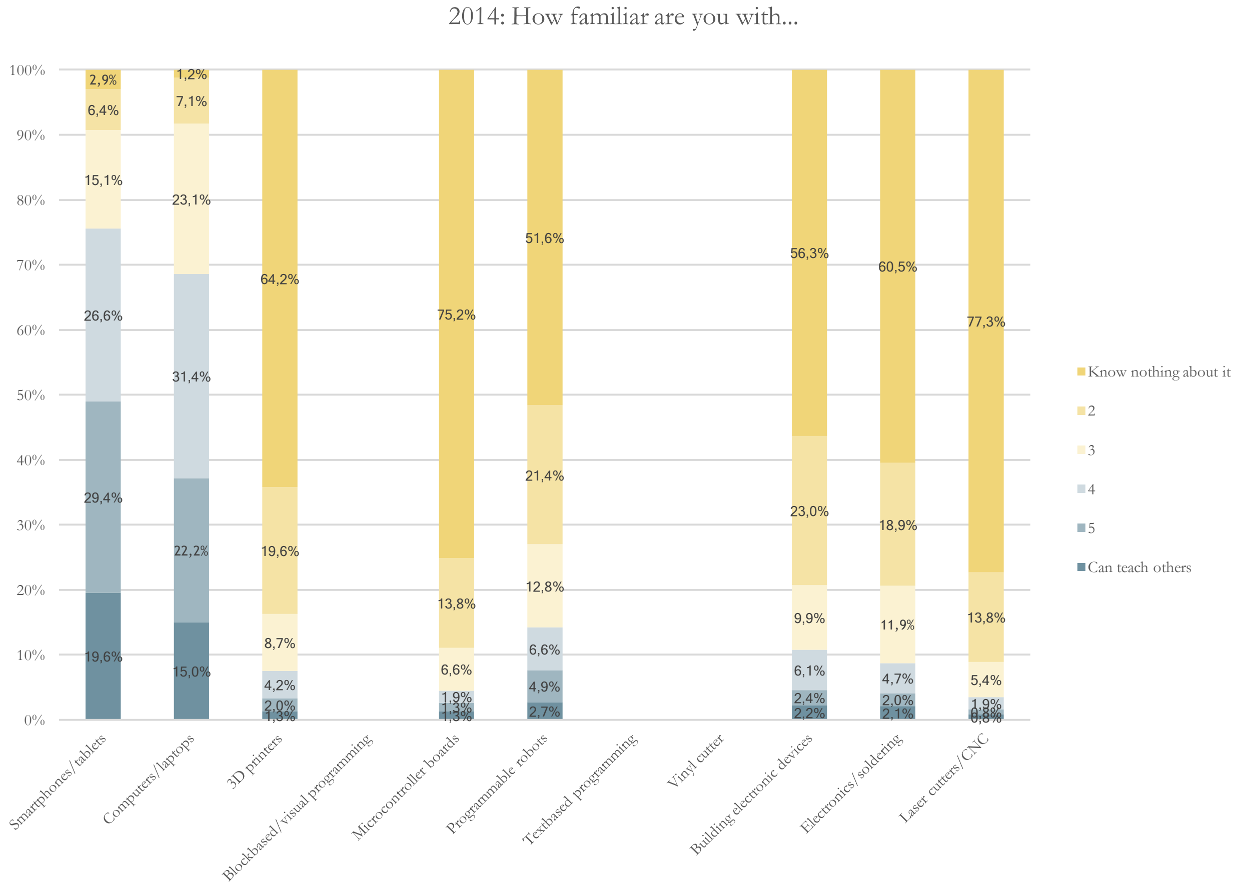

Figure 17: Students from 2014 baseline survey's self-perceived knowledge of a range of technologies used in school FabLabs. On the original survey, there were separate questions for smartphones and tablets. Here, the average of responses on these two questions is reported as Smartphones/tablets for the sake of comparison with the 2016 survey. Further, neither of the programming questions nor the vinyl cutter question were parts of the 2014 survey. Arranged in the same order as Figure 16.

Comparing Figure 16 and Figure 17 reveals, that the FabLab group had significantly higher self-reported knowledge of all digital fabrication technologies than did the students from the 2014 survey. The only technology surveyed in both 2014 and 2016 that the FabLab group did not report being more knowledgeable about than the 2014 group was electronics and soldering. Since the test for significance was done carried out both using a Holm-Bonferroni correction of p-values and treating schools as random variables (see section 3.1), this result was robust. Thus, we conclude, that students in the FabLab@School.dk project on average perceived of themselves as more knowledgeable about digital fabrication technologies than they would have in 2014 at the beginning of the FabLab@School.dk project. This effect could be due to the FabLab@School.dk project, or it could be, that it is an effect in society at large. After all, the technological landscape of the society had changed a lot since 2014. It is for this reason that we included a control group in our endline survey.

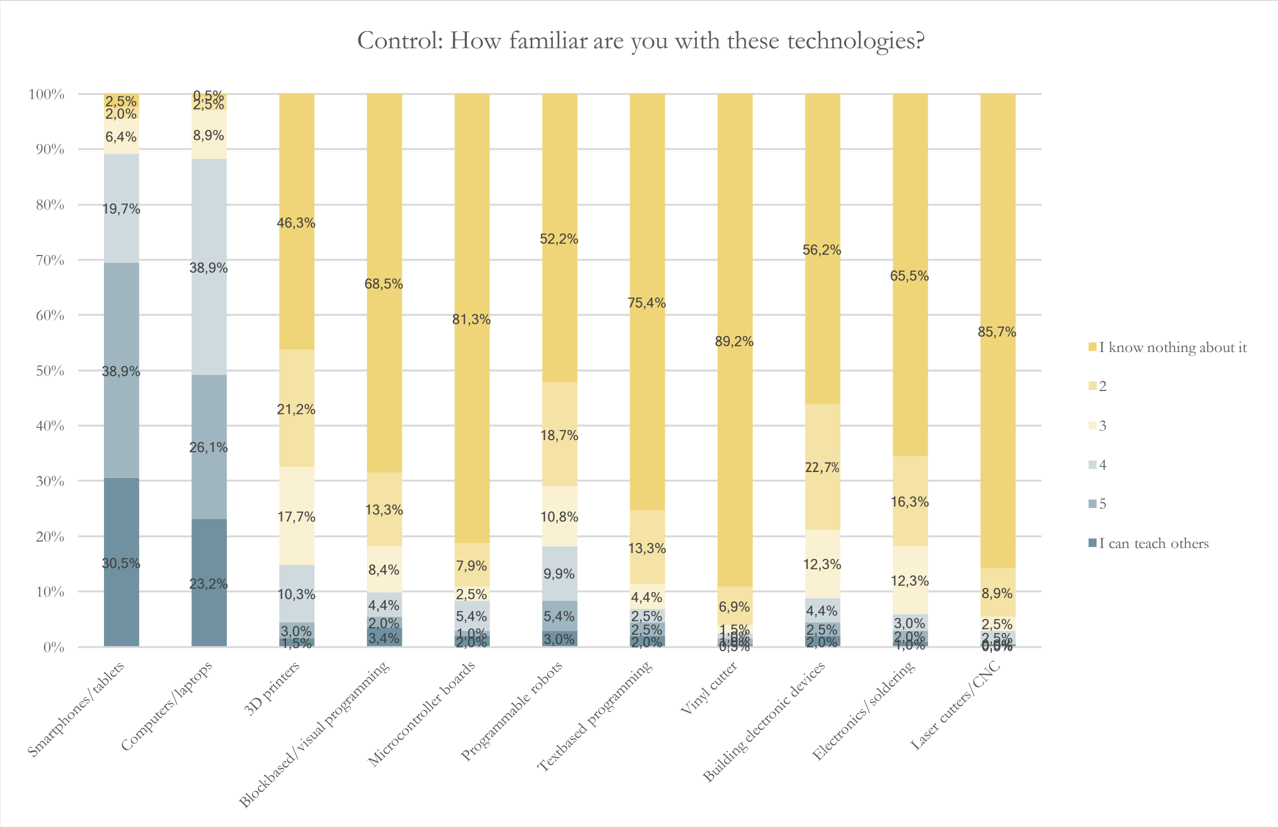

Figure 18: Control group students' responses self-perceived knowledge of technologies. Arranged in the same order as Figure 16.

For all of the technologies in Figure 16 and Figure 18, the trend is that students from the FabLab group on average rated themselves higher than did students from the control group. When comparing the two groups on each technology without taking the variation between schools into account, this difference was statistically significant for 3D printers, Laser cutters, Microcontroller boards, textbased programming, vinyl cutters, and block-based/visual programming. This result was to be expected since these technologies were and are integral parts of the FabLab@School.dk project. However, when using school as a random variable in our statistical model, and thus when taking the variation between schools within each group into account (see section 3.1), we cannot conclude, that the difference is statistically significant. That is, we cannot conclude, that the results did not happen by chance. The only exception is 3D printers. Here the average weighted score of the control group students was 2.1, whereas on average, FabLab group students rated themselves as 2.8 on the scale of 1 to 6 of how familiar they were with the 3D printer. This difference was statistically significant. Thus, we conclude that regardless of the school, digital fabrication was introduced to, students did on average attain higher levels of self-perceived knowledge of 3D printers than they would have if their schools had not been part of the project.

4.6.1. Differences between schools within the FabLab group

As depicted in Figure 19, student responses to the question of how familiar they were with the different technologies showed large variations between the four groups of schools (see section 4.3). For example, 42 percent of the students from group one were above the average score (3.5) on 3D printers. For group 2, the number was 46 percent, for group 3 it was 20 percent, and for group 4 it was 19 percent. Thus groups 1 and 2 fared better in students' self-perceived knowledge of the 3D printer than did groups 3 and 4. The overall trends are better viewed when comparing the (weighted) averages of student responses on each technology.

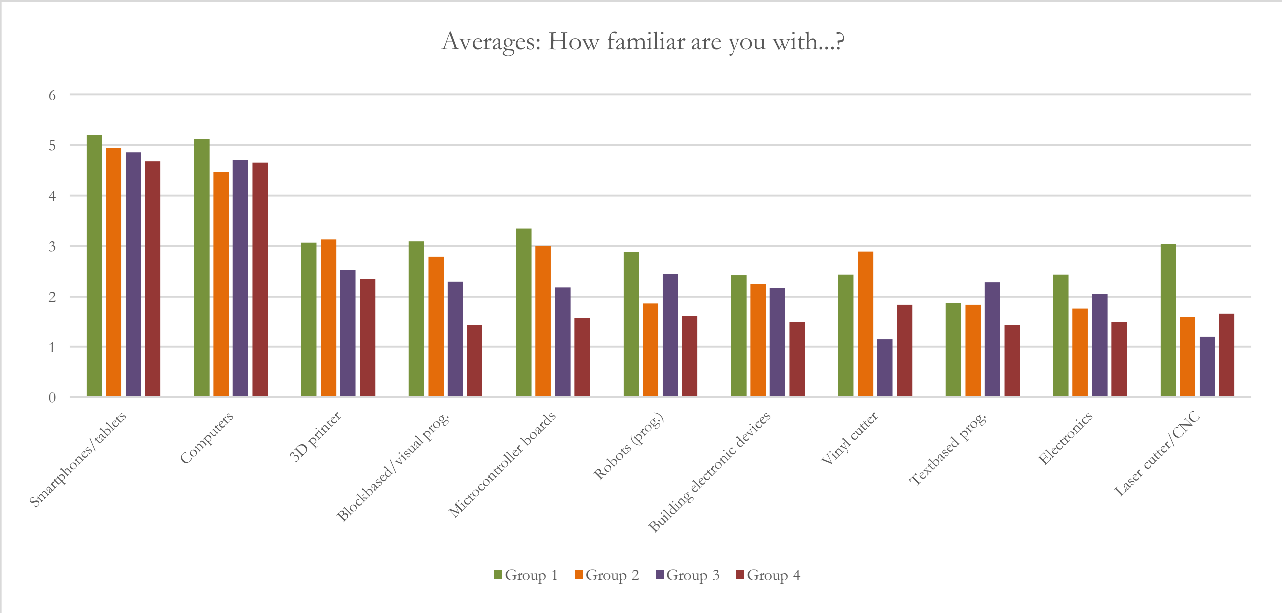

Figure 19: Averages of groups' self-perceived knowledge of technologies.

For all technologies except text-based programming, 3D printers and vinyl cutters, students from group one rated themselves more highly than students from the other groups. By contrast, students from group four rated themselves lower than students from all other groups on all digital fabrication technologies except laser and vinyl cutters. However, this group did not rate themselves lower than the other groups in regards to computers in general, which suggests that their lack of self-perceived knowledge of digital fabrication technologies was not just due to self-perceived lack of understanding of IT in general or low self-esteem. Students from group two on average rated themselves more highly than the other groups on vinyl cutters and 3D printers, whereas students from group three on average had the highest self-perceived knowledge of text-based programming and the second-highest self-perceived knowledge of building electronic devices from scratch, and of electronics and soldering in general.

4.7. Where did the students learn to use digital fabrication technologies?

We were surprised that so many of the students in the control group had worked with digital fabrication technologies. In Figure 20 and Figure 21, we compare responses from the FabLab and control groups with regards to where the students had learned to use the different technologies.

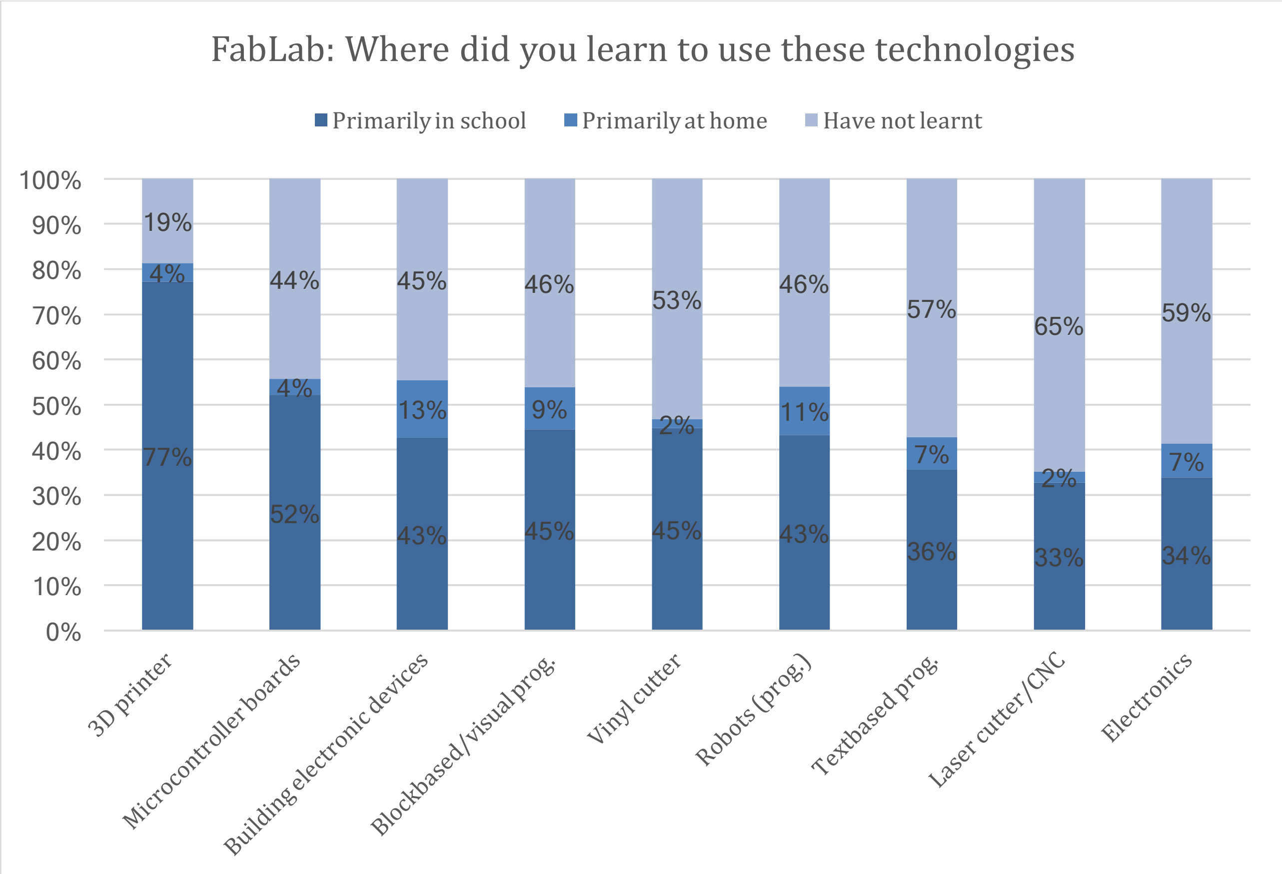

Figure 20: FabLab students' responses to the question of where they learned to use the given technologies. Ordered by "Primarily in school".

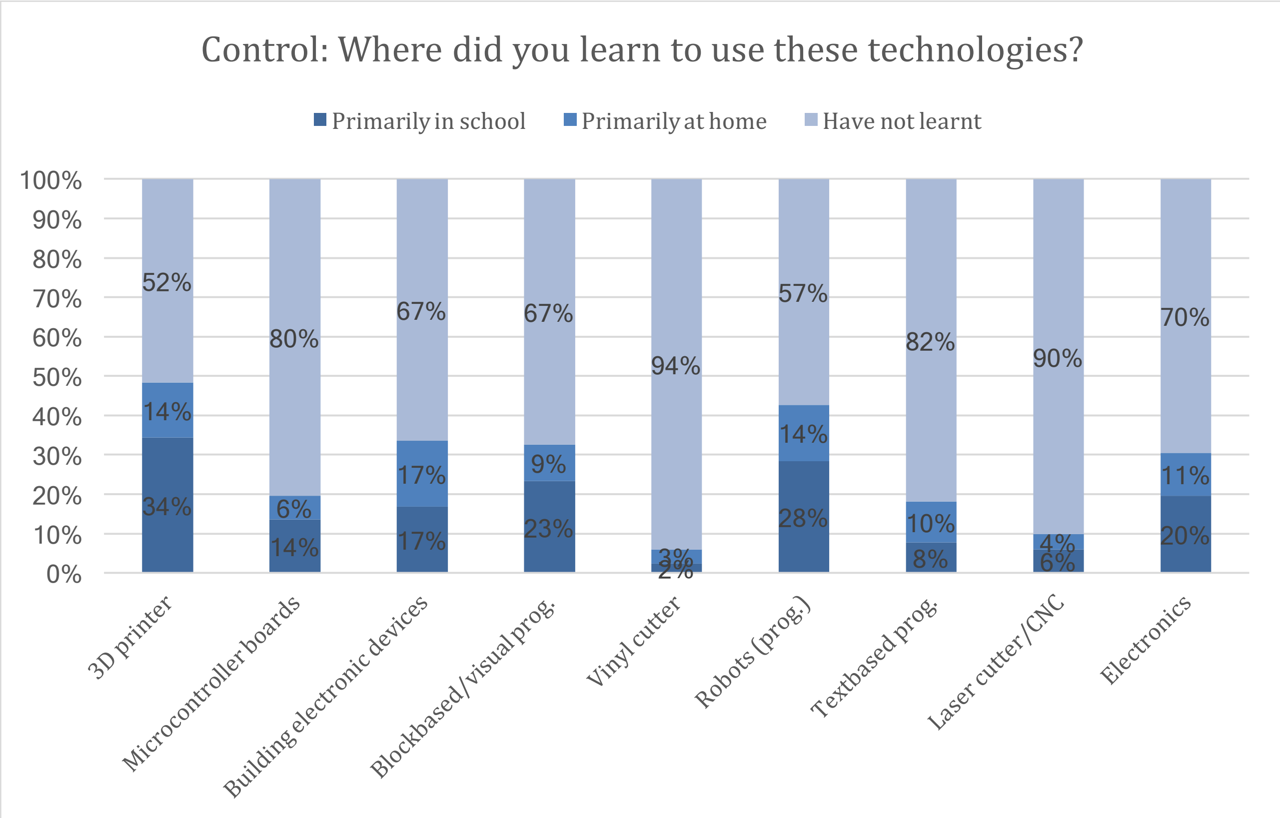

Figure 21: control group students' responses to the question of where they learned to use the given technologies. Arranged in the same order as Figure 20.

Figure 20 and Figure 21 show that it was more common for the control group students than the FabLab students to have learned to use the included technologies at home. Thus one reason the control group students had used more digital fabrication technologies than we had expected, could be because some of them had been able to use them in out-of-school contexts. However, 34 percent of the control group students still reported that they learned to use 3D printers in school. According to their answers, 28 percent of the control group students learned to use programmable robots in school, 23 percent learned to use block-based or visual programming, and 20 percent learned about electronics and soldering, while 17 percent learned to build electronic devices from scratch and 14 percent learned to use microcontroller boards. In conclusion, students from the control group had worked quite a bit with the technologies that were included in the FabLab@School.dk project, and it seems plausible that this is one of the reasons why we did not see statistically significant differences in answers between FabLab and control groups on a range of the questions where we had expected to see such differences. When comparing the FabLab and control groups on where they had learned to use the technologies, however, it was more common for FabLab students to report that they had learned to use the technologies in school. This difference was statistically significant for 3D printers, laser cutters and vinyl cutters, text-based programming, microcontroller boards, and building electronic devices from scratch. In conclusion, according to their answers students from the FabLab group had learned to use digital fabrication technologies in school more frequently than students from the control group. The only exceptions were programmable robots, electronics and soldering, and blockbased/visual programming.

In earlier sections of this report, we have showed how large variations between groups of FabLab schools made comparisons between the FabLab and the control groups difficult. If there would also be large differences between where students within the FabLab group learned to use the technologies, the variations between groups of schools could be caused by students in some schools spending more time with the technologies outside of school than students from other groups. Figure 22 displays the differences between groups one, two, three, and four in regard to where students claimed to have learned the involved technologies.

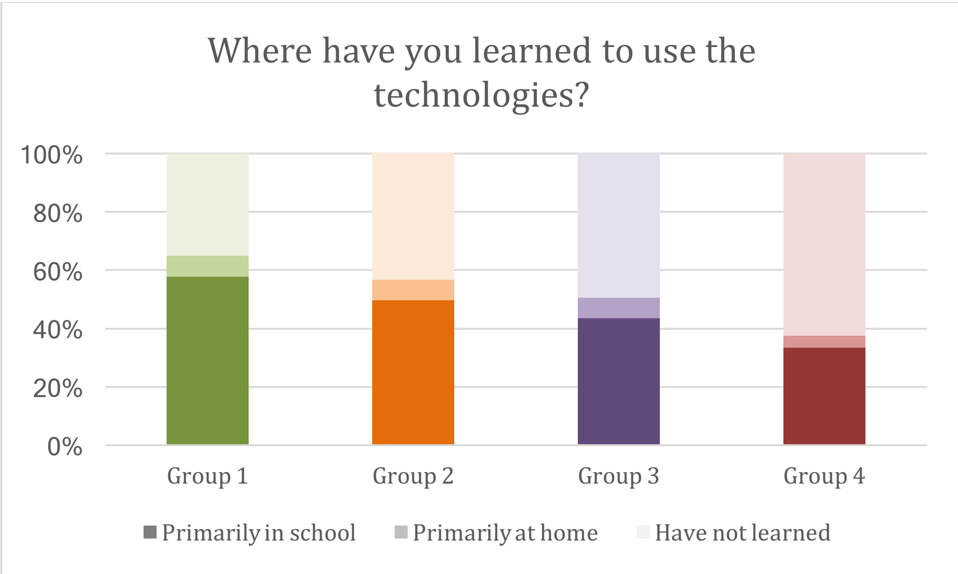

Figure 22: Percentage of the responses in which students in each group reported to have primarily learned to use a technology at school, in the home, or not at all.

As seen in Figure 22, the number of responses in which students claimed to have learned to use digital fabrication technologies at home was seven percent in groups one, two, and three, while it was four percent for group four. Thus in the cases of group one, two, and three, the variation in number of technologies used between schools was only due to more technologies being used in school in group one than group two in which more technologies were used than in group three. In group four fewer technologies were used both in and out of school.

4.8. Conclusion: Technologies, implementation and knowledge

Compared to the 2014 group, the FabLab group on average had an increase in self-perceived knowledge of 3D printers, laser cutters, vinyl cutters, building electronic devices, microcontroller boards, programmable robots, text-based programming, and blockbased/visual programming. Thus FabLab students improved their understandings of digital fabrication technologies.

Students in the Fablab group had been exposed to more digital fabrication technologies, than was the case in the control group. Further, the FabLab students had more experience in using the technologies to work on own ideas, and they had to a higher degree worked with the technologies in school settings.

Thus FabLab students gained experience with a range of digital fabrication technologies. Compared to the control group, students from the FabLab group to a higher degree reported that they had primarly gained knowledge about 3D printers, laser cutters, vinyl cutters, text-based programming, microcontroller boards, and building electronic devices from scratch in school. Further, comparing FabLab and control groups revealed that students in the FabLab group on average reported a higher level of knowledge of 3D printers.

The survey reported here, was designed as a comparison between an experimental group (FabLab group), a control group, and corresponding data from a 2014 survey. However, these comparisons were difficult to make for two reasons. First, the control group students had to an unexpectedly large extent been exposed to digital fabrication. Second, there were very large variations in the implementations of digital fabrication within the FabLab group. Both comparisons between the FabLab, control, and 2014 groups, and the variations within the FabLab group in regard to the use and knowledge of technologies were explored throughout chapter 4. There is no central strategy in the FabLab@School.dk project with regards to how many and which technologies to implement and how to implement them. We see this as the main reason for the large amount of variation that we found within the FabLab group in regard to which technologies and how many technologies, the schools used.

The data discussed in chapter 4, suggested a correspondence between the number of technologies used, the number of technologies used to work with own ideas, and the self-perceived knowledge of these technologies.

5. Students' design knowledge

In this chapter, we explore how students reported in answer to questions regarding design, design processes, and a designerly stance towards inquiry.

5.1. Designerly stance towards inquiry

As stated in the introduction the survey consisted of several different types of questions. More specifically, the questions ranged from items with Likert-type scales asking about opinions or self-perceived abilities, through multiple-choice tasks, to open-ended problems. One such problem was the task of how to prevent seniors with dementia getting lost (and sometimes dying before they were found) from their care homes. This was an example of a design problem, a so-called *wicked problem* (Buchanan, 1992). It is a characteristic of wicked problems that they are indeterminate. That is, they do not have one true solution. Thus, by definition, suggesting a solution to a wicked problem requires judgment. According to the pragmatist design literature (e.g. (Löwgren & Stolterman, 2004)), this judgment is exercised on the basis of knowledge generated in an iterative design process, entailing inquiry into the problematic situation. As described by Cross (Cross, 2011), a designer would approach the wicked problem by means of an investigative (design) process. However, as evidenced in Hjorth et al. (Hjorth, Iversen, Smith, Christensen, & Blikstein, 2015), processual thinking and complex problem-solving were not part of the current Danish school reality in 2014. That is, the students were inclined to suggest solutions and invent ideas, rather than approaching the problem as a complex challenge in need of further investigation. In (Christensen, Hjorth, Iversen, & Blikstein, 2016), it is described how this question distinguishes between students suggesting a designerly stance towards inquiry and those suggesting a stance of technical rationality. Students with a stance of technical rationality tend to suggest finalized solutions based on their (lack of) existing knowledge rather than suggest paths for inquiry into the problematic situation. In the 2014 survey, fewer than 3 percent of the students suggested taking a designerly stance towards inquiry. Rather, students in the 2014 survey suggested finalized solutions such as better fencing, locks on the doors, more personnel, or tracking devices. In our 2016 survey (reported here), we included the same question with the same wording, with the aim of investigating whether more students would suggest a designerly stance towards inquiry this time. Students in the FabLab@School.dk project had in many cases been engaged in designing solutions to real-world problems, and had used the design process model developed in the Child–Computer Interaction Group at Aarhus University (see section 5.4, (Hjorth, Smith, Loi, Iversen, & Christensen, 2016; Smith et al., 2015)). Compared to most other design process models used in educational practices, this model places more emphasis on field studies—on inquiring into the problematic situation of real-world problems, as well as on argumentation and reflection, throughout the entire design process. The explicit focus on exploration and reflection in the context of real-world problems gave up hope that more students would take a designerly stance towards inquiry when faced with the wicked problem on the survey.

The dementia case was a real-world problem that was being discussed in the Danish media at the time of the 2014 survey.[2] The wording of the open-ended question translates from Danish to the following:

[2] The number of elderly refers to a Danish context (population approx. 5.7 million).

> At the beginning of the year 2014, nine grandparents disappeared from their care home because of their loss of memory (dementia). The problem for the care home is how to create security for these seniors without taking away their freedom.
>
> If you were asked to solve this problem, what would you do?[3]

Posing a good question that could probe the current state/understanding of *design*, *process*, and *inquiry* among the students in a valid way was difficult. We are aware that the framing of the question could have prompted respondents to come up with a solution rather than a process. Nevertheless, as described in (Christensen et al., 2016), a comparison of answers to this question with those of budding university-level designers did seem to significantly distinguish between stances of technical rationality and more designerly stances.

In our report on the 2014 survey, we wrote:

> ... it is our assumption that responses to similar questions, between the baseline survey and the endline survey, will reveal a shift in the number of students who have been exposed to design processes in FabLab@School activities. The assumption is, that it will be more frequent for the latter to suggest processual and investigative approaches to complex challenges. (Hjorth et al., 2015)

[3] Translated from Danish.

As can be seen in Figure 23 below, this was indeed the case, but only for a very small number of students.

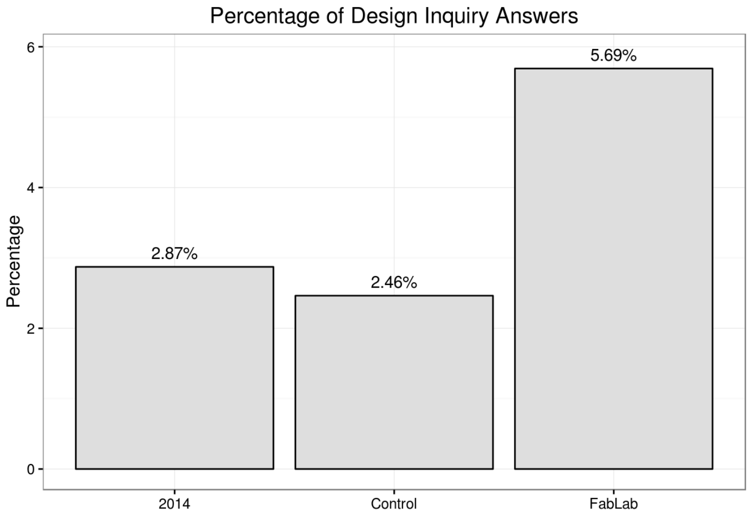

Figure 23: Percentage of students suggesting an inquiry while responding to the dementia problem. Numbers are shown for the 2014 survey, the control group, and the FabLab group.

As the Figure 23 shows, 5.69 percent of the FabLab group students suggested taking a more designerly stance towards inquiry. In the control group, the number was 2.46 percent. Since the percentage among the FabLab students is more than double that among the control group students, this could at first seem like a significant result. Once school was included as a random variable in order to control between-school variation, however, the difference was not statistically significant. Again, this points to a large variation between the schools. At the same time, fewer than 6 percent of the FabLab@School.dk students were suggesting an inquiry: the rest were coming up with finalized ideas such as fencing, tracking, or hiring more personnel (as in the 2014 survey). There was therefore insufficient data to compare the groups of schools. In the FabLab@School.dk project, inquiry and field studies have had a prominent position, and the teachers from all the schools had participated in conferences, workshops, or co-development of activities with the research group, which has emphasized inquiry and investigation. Teachers from six of the FabLab group schools had taken a master's course on design processes and digital fabrication, thus the idea of a designerly stance towards inquiry should not have been new to the teachers of the FabLab group students. However, the lack of a statistically significant difference between the control and the FabLab groups highlights that a designerly stance towards inquiry is perhaps not easily acquired.

5.2. Development of design literacy

It is one thing to know technology, another to be able to use it, and yet a third thing to understand how it was created, how it functions, and how it might influence our lives. These last questions are difficult to probe in a questionnaire—not least because they are difficult for 11–15 year olds to understand, with the associated result that it is also difficult to judge their knowledge on such complicated questions. However, since one of the aims of the FabLab@School.dk project was precisely to promote such understandings, we asked students from the FabLab group to reflect on to the degree to which the projects with digital fabrication technologies had helped them understand, reflect on, and work with technologies in a broader sense.

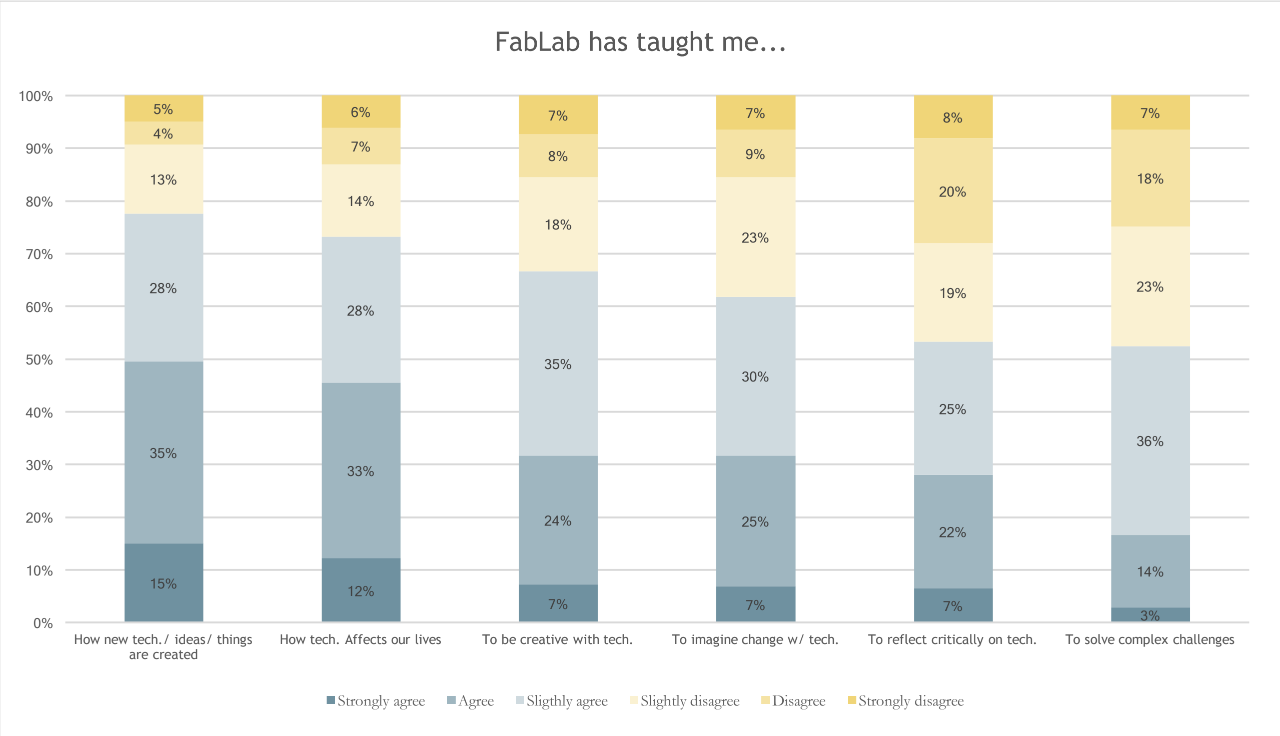

Figure 24: The degrees to which FabLab students agreed with proposed learning outcomes. Ordered by strongly agree.

As can be seen in

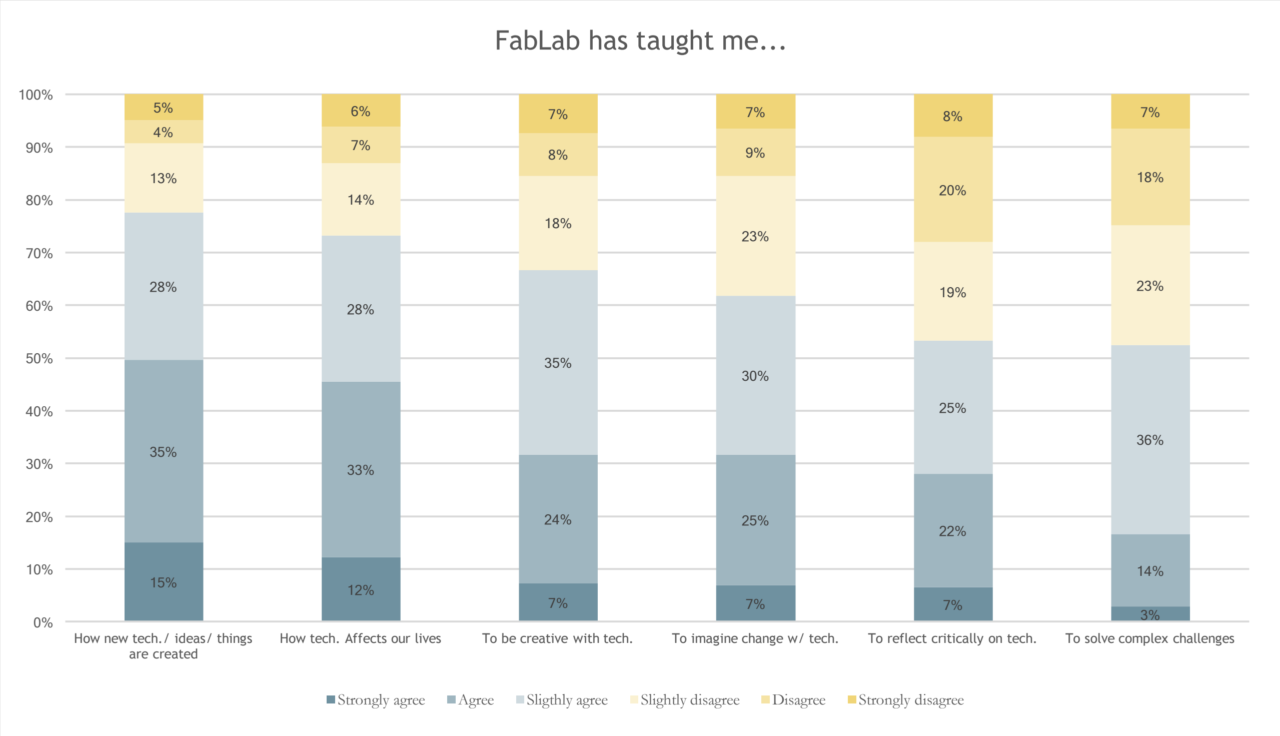

Figure 24, half of the students (50 percent) in the FabLab group either agreed or strongly agreed that the projects with digital fabrication technologies had helped them understand how new technologies are created; 9 percent disagreed or strongly disagreed, whereas 41 percent either agreed slightly or disagreed slightly. On average, the students in the FabLab group rated this question as 4.3 on a scale of 1 to 6 (the average being 3.5). On the question of whether or not projects with digital fabrication technologies had helped them to understand how technology is affecting the way we live, the average student score was 4.1. Thirteen percent of the students disagreed or strongly disagreed, whereas 46 percent agreed or strongly agreed. As in the question on understanding how technologies are created, 41 percent of the students either agreed or disagreed slightly. On average, students agreed that working with digital fabrication technologies had improved their ability to work creatively with technology (avg. 3.8), imagine how to create change with technology (avg. 3.8), and reflect critically on their own use of technology as well as that of others (avg. 3.5). More than half (52 percent) of the students in this FabLab group answered that working with digital fabrication technologies had to some degree helped them to solve difficult or complex challenges. However, most of these responses were in the slightly agree category (36 percent of the total responses). Only 14 percent of the students agreed, and 3 percent agreed strongly. Thus while students in the FabLab group on average reported that they had become better at understanding how technologies are created, how they affect our lives, how to work creatively and imagine change with technologies, and how to reflect critically on their use, these students on average did not see how this work had also strengthened their abilities to solve difficult and complex challenges in general. While we might have predicted that working in design processes with the aim of solving complex challenges would prepare students for future complex challenges in general, it is possible either that these students did not fully appreciate their own development, or that this development did not take place. In many schools, students had fewer projects with complex challenges than expected, and therefore if students' did not develop abilities to solve complex challenges, it could point to the possibility that the development of what we have elsewhere termed design literacy (Christensen et al., 2016; Smith et al., 2015) takes more time than was spent on such projects on average within the FabLab group. It could of course also point to missing qualities of the implementations of digital fabrication. The questionnaire did not yield any data to distinguish between types of implementation, but as reported above (se section 4.3), interviews with students pointed to four archetypes of implementation. Based on these four types, school were divided into four groups. In the next section, we will compare the responses of students from these groups.

5.3. Development of design literacy among groups of schools

As can be seen in

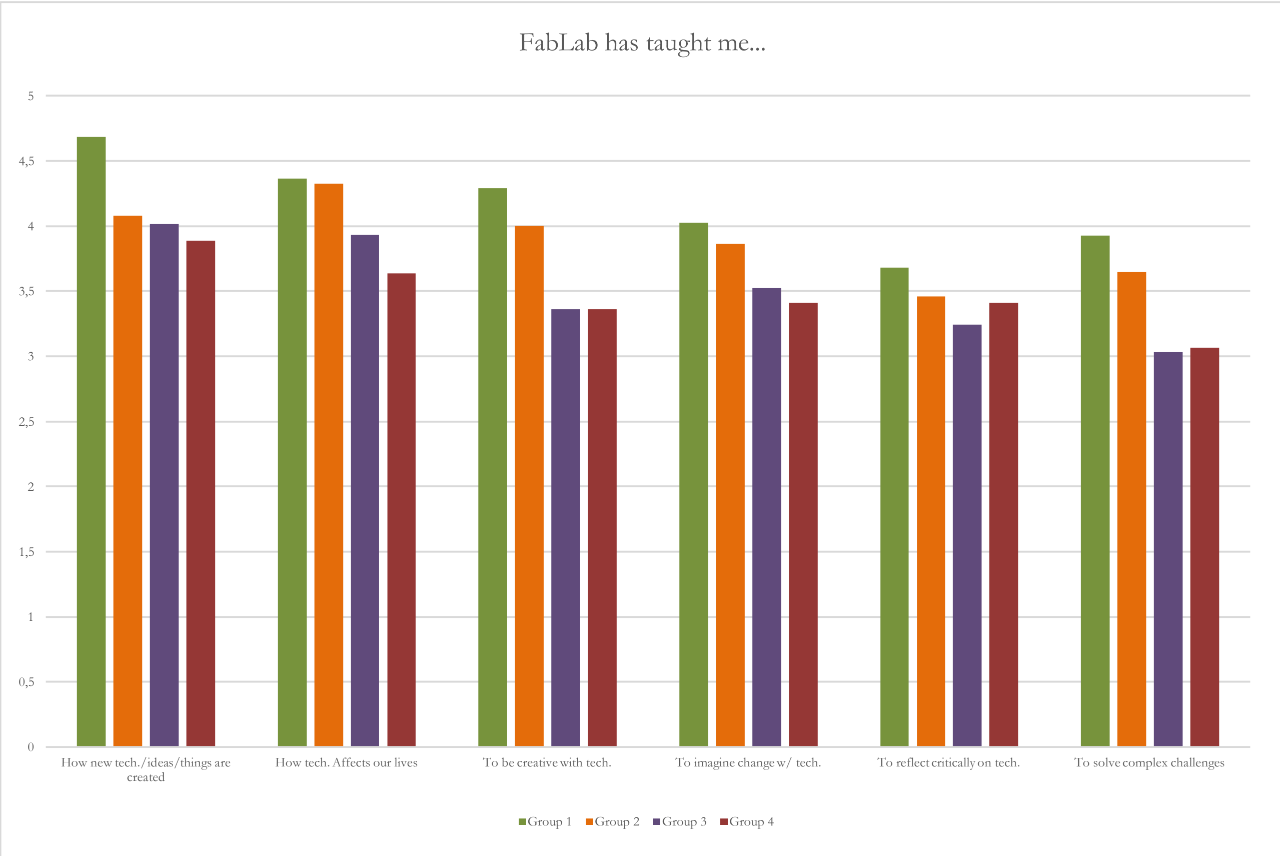

Figure 25, there were large differences between the groups of schools in regard to students' self-perceived outcomes of their work with digital fabrication. Further, these differences followed one of the trends described above—that students from group one seemed to have benefited the most from work with digital fabrication technologies, whereas group four seemed overall to have benefited the least. Groups two and three were placed between groups 1 and 4 on most questions.

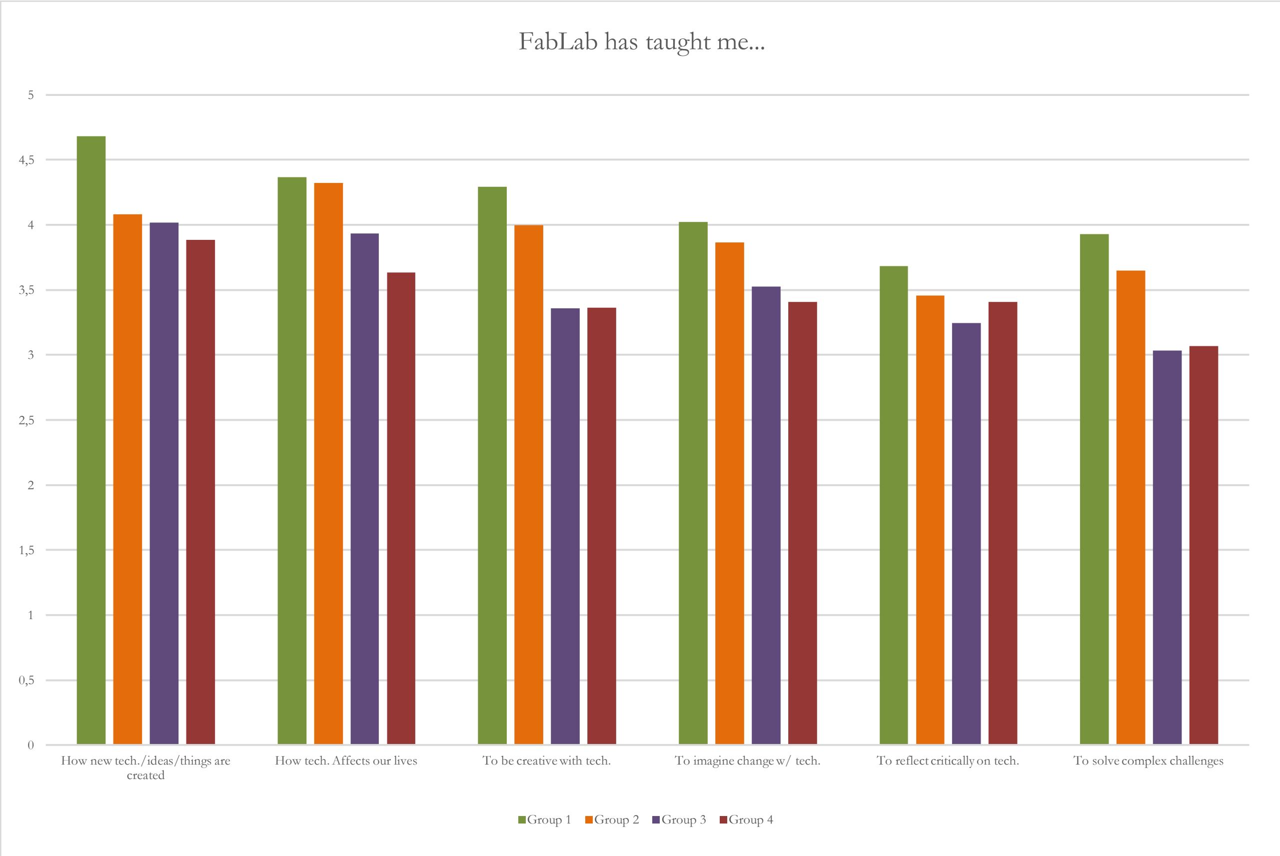

Figure 25: Average responses from students within groups 1 through 4 on questions regarding their outcome of work with digital fabrication technologies in school. Note, that the average of the scale (which was from 1 to 6) is 3.5. Ordered by average score for the entire FabLab group.

On all of the questions reported in Figure 25, more than 50 percent of the students in the overall FabLab group answered that they did to some extent agree. As reported above, however, the average response on whether or not work with digital fabrication technologies had helped the students to solve difficult or complex challenges was below the 3.5 average. As can be seen here, only group one and two students on average scored the question above 3.5. Thus only in these schools did students on average agree that working with digital fabrication technologies had prepared them for taking on complex challenges. If the development of skills for taking on these kinds of challenges is a priority of work with digital fabrication technologies, it therefore seems important that these technologies be used in ways that mirror the approaches taken by school groups one and two rather than three and four. The responses followed the same pattern on the question of whether or not work with digital fabrication technologies had helped the students to work creatively with technology. One might therefore suggest that working creatively with technologies is a prerequisite if working with digital fabrication technologies is to further students' abilities to take on difficult or complex challenges. All groups on average agreed that working with digital fabrication technologies had helped them better understand how technologies, ideas, and things were created. However, group one stood out, with a very high average of 4.7. On average, students from all groups agreed that working with digital fabrication technologies had helped them understand how technology was affecting their lives, but only students from group one on average responded that they had become better at critically reflecting on their own and others' use of technologies. Being able to imagine how to create change with technology was something on which students from group one, two, and three on average responded they become better at (4.0 and 3.9, and 3.5 respectively), whereas students from group four did not (3.4).

In sum, students from all four groups on average reported that working with digital fabrication technologies had helped them to better understand how technologies, ideas, and things are created, as well as how technology is affecting our lives. Further, the data suggests that in groups where students on average reported that they had become better at working creatively with technology and at solving complex challenges, these gains were greater.

5.4. Structuring the design processes with the design process model

As part of the FabLab@School.dk, the Child–Computer Interaction Group at Aarhus University developed the AU design process model depicted in Figure 26 (Hjorth et al., 2016; Smith et al., 2015).

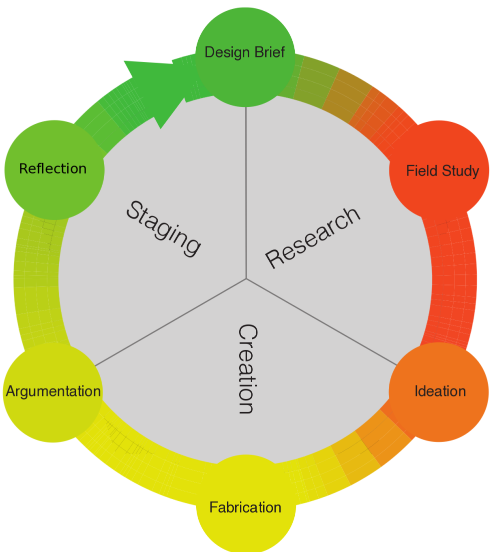

Figure 26: The AU design process model.

This process model differs significantly from other design process models used in educational practices (see (O'Brien, 2016) for an account of different design process in education) in its enhanced focus on field studies, a feature that corresponds with teaching material, which was developed by AU, and which was used by most teachers in the FabLab@School.dk project. It was up to the teachers whether or not they wished to use the design process model, but most schools have chosen to implement it in their teaching. In the FabLab group a total of 69 percent of the students reported that they used the model, 11 percent did not know, and 20 percent claimed they had not used it. Figure 27 explores students from the FabLab group's self-perceived knowledge of the different parts of the AU design process model.

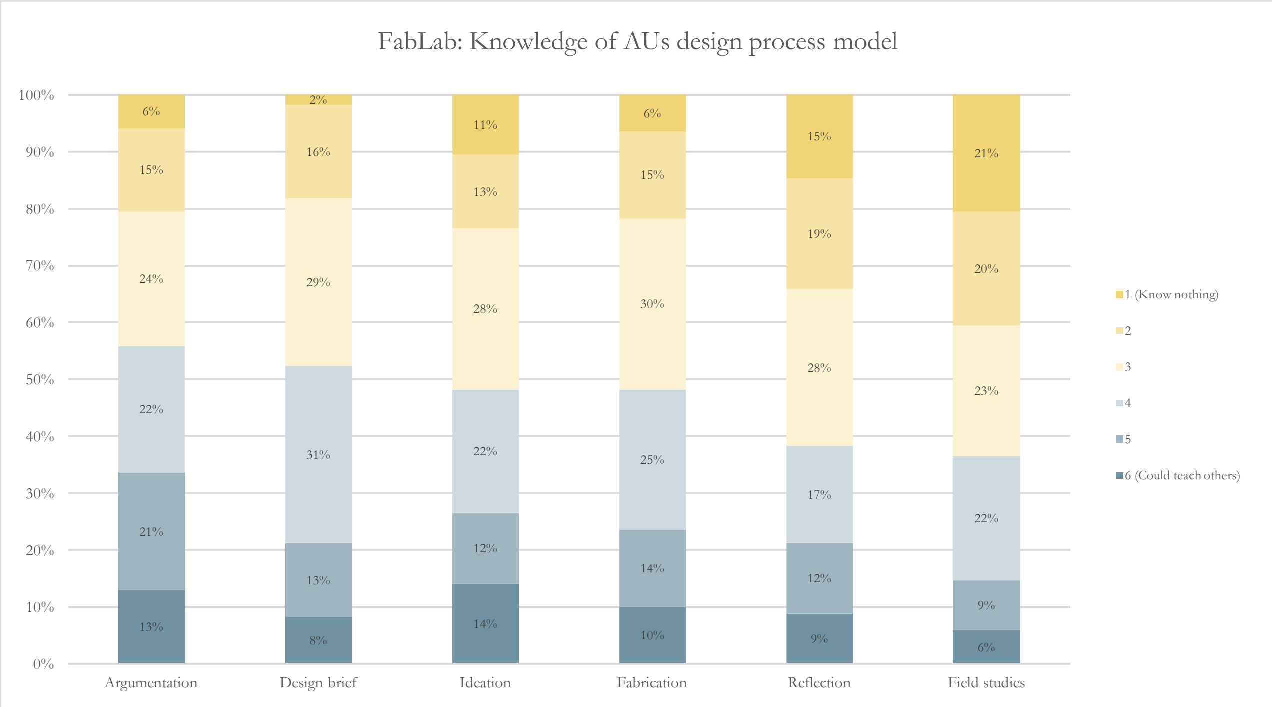

Figure 27: Students from the FabLab group's self-perceived knowledge of the various parts of the AU design process model. Students were asked to rate themselves on a scale of 1 (I know nothing about it) to 6 (I could teach others about it). Ordered by the sum of entries in categories 4, 5, and 6.

As depicted in Figure 27, more than 50 percent of the students in the FabLab group perceived of themselves as belonging to category four, five, or six in regard to the argumentation (56 percent) and design brief (52 percent) parts of the process. Between 40 and 50 percent of students placed themselves in this category in regard to ideation (48 percent) and fabrication (48 percent), whereas below 40 percent reported this for reflection (38 percent) and field studies (37 percent). Thus the data suggests that students on average found field studies and reflection to be the most difficult parts of the process or that there had been less emphasis on teaching these phases of the process.

5.5. Use and knowledge of the design process model in groups of schools

Only students who reported that they had used the design process model were asked how well they knew the different parts of the model. There were, however, variations between the groups of schools in regard to the degree to which they had used the design process model. These variations are depicted in Figure 28 and Figure 29.

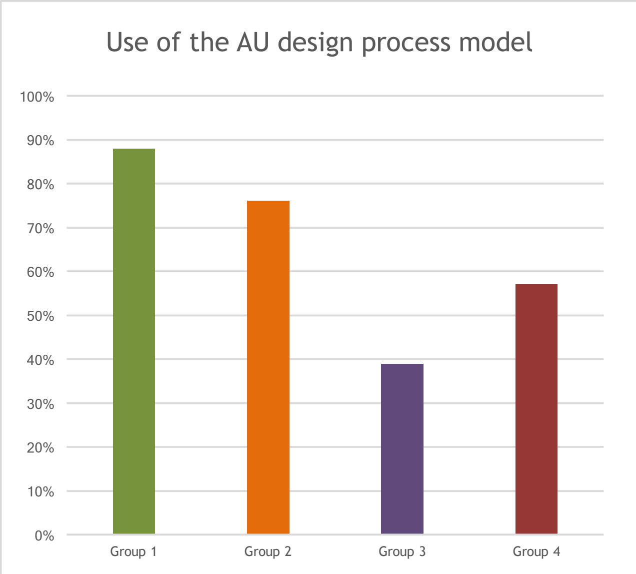

Figure 28: Percentages of students from each school group that reported using the design proces model.

As can be seen in Figure 28 there were large variations between the groups in regard to their reported use of the AU design process model. Eighty-eight percent of students from group one reported that they had used the model. The same was true for 76 percent of the students in group two. In group three, only 39 percent of the students reported that they had used the design process model. Fifty-seven percent of the students in group four reported that they had used the model. Students from groups three and four were more heterogeneous in their responses to whether or not they had used the model in school. Students' self-perceived knowledge of the various parts of the AU design process are shown in Figure 29.

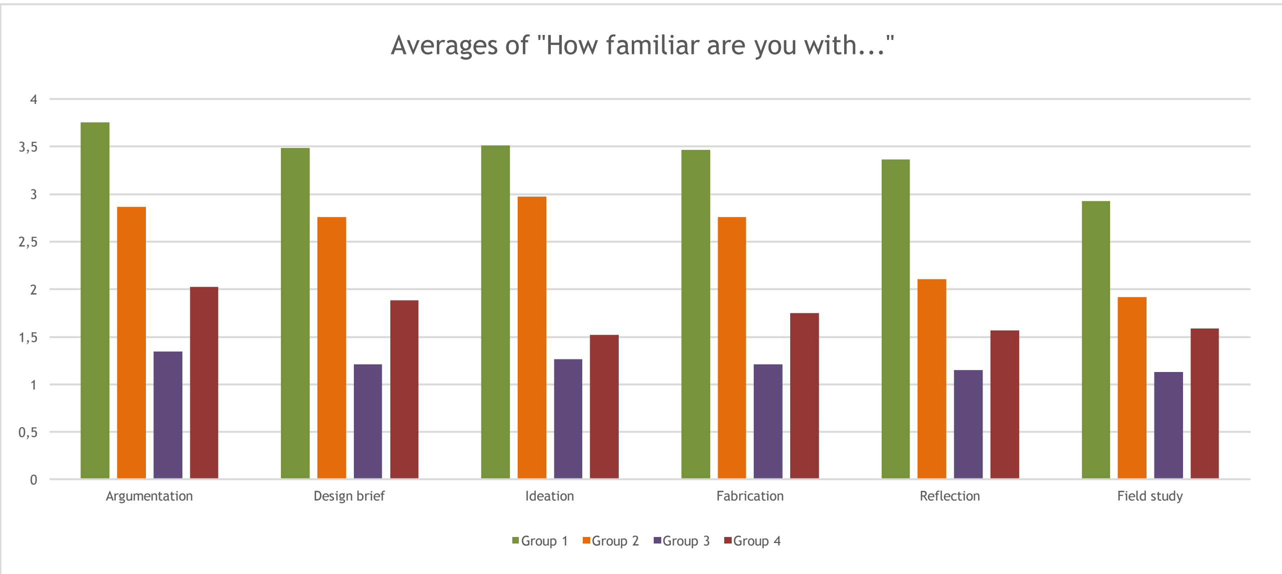

Figure 29: Group averages of the question of how familiar students are with the different parts of the design process model. Ordered by student averages in the FabLab group in total

When looking at the averages of self-perceived knowledge of the different parts of the design process model within the different groups depicted in Figure 29, students from group one on average rated themselves higher than students from all other groups on all items. Second on all parts of the model were students from group two. The students from group three who had responded that they had used the design process model rated themselves below all other groups on average. Students from group four on average rated themselves between students from groups two and three. The data suggests that teachers from group one had used the design process model more than teachers from groups two, four, and three. In sum, the data suggests a correspondence between the number of students from a given group that reported using the model and the self-evaluated level of these students. When the number of students who responded they had used the model and the self-perceived knowledge of these students both follow the same pattern, it seems plausible to us that this has to do with the emphasis placed on the design process model or the amount of time spent on projects structured around this model. This leads us to conclude that the data suggests that students from group one had worked more on projects structured around the AU design process model, than had students from group two, who in turn had worked more on such projects than students from group four. Finally, the data suggests that students from group three had worked the least on projects structured around the AU design process model.

When comparing the use of the AU design process model to students' self-perceived outcomes of the work with digital fabrication, the data suggests that the more students work in processes structured around the design process model, the more they had been taught to solve complex challenges and reflect critically on the use of technology (as measured by self-evaluation). Further, group three and four scored themselves at equal levels in regard to the degree to which work with digital fabrication had helped to work creatively with technology. Since students from group four had worked with fewer technologies and had used fewer technologies to work on own ideas than students from group three, it seemed plausible, that students from group 3 should have been gained more in respect to being creative with technology from working with digital fabrication. It seems, however, that not structuring the work with digital fabrication around the design process model, hindered students from group three in getting the outcome that would have been expected. Thus our data suggests that students gain more in regard to complex problem solving, critical reflection on the use of technology, and the ability to work creatively with technology, when their work with digital fabrication is structured around a design process model which is both systematic and iterative.

5.6. Conclusion: Towards design literacy

In conclusion, we do see some steps towards design literacy among some students from some schools, but the results highlight that this is a very difficult goal for teachers and students to work towards. In our interpretation, the data suggests that scaffolding and structuring the work with digital fabrication in schools around a design process model like that developed within the FabLab@School.dk project furthers the development of design literacy.

As reported above, there were large differences between the school groups. In groups one and two, students on average reported that they had become better at solving difficult or complex challenges. When looking at the use of the design process model as evidenced by student responses to questions on whether they had used the model and the degree to which they knew the different parts of the model, our data suggests that students gain more in regard to complex problem solving, critical reflection on the use of technology, and the ability to work creatively with technology, when their work with digital fabrication is structured around a design process model. We therefore find it plausible to suggest that in schools where the design process had to a high degree been structured and scaffolded by the use of a design process model, students came to feel more secure about thinking and acting innovatively (with technology) on societal challenges. However, more research is needed in order to substantiate this claim.

We asked the students to evaluate their outcome of work with digital fabrication in school, and on average, students from the FabLab group reported that work with digital fabrication had helped them to understand how new technologies, ideas, and things were created, to imagine how they could create change with technology, and to be creative with technology. In our interpretation, this translates to the conclusion that according to the students themselves, as a result of the FabLab@School.dk project they had become better at *thinking and acting innovatively with technology*.

Further, the students on average agreed that as a result of working with digital fabrication they had become better at understanding how technologies affect our lives and at critically reflecting on their own and others' use of technology. However, they did not on average agree that they had become better at solving difficult or complex challenges. In our interpretation, this translates into the conclusion that contrary to students from the groups 1 and 2, students in the FabLab group did not on average agree that they had developed better abilities for using the technology "on societal challenges." This discrepancy emphasizes the variation between implementations among groups of schools. Thus many students did not experience the long-term commitment to working with complex problems in design processes.

As mentioned previously, within the FabLab@School.dk project, we viewed students' "abilities to think and act innovatively (with technology) on societal challenges" as a key goal of education in the twenty-first century. We hypothesized that the project had the potential to further such abilities. In line with this, we have elsewhere (Smith et al. 2015, Christensen et al. 2016) used the term "design literacy" to denote those parts of design competence to take on complex or wicked problems which are relevant to all students in the twenty-first century. In our investigations of what it means to be design-literate, we have singled out a designerly stance towards inquiry as an important aspect. In the survey reported here, we used the DeL tool (Christensen et al., 2016) to gauge the students' stances towards inquiry. This did not however allow us to conclude that students had changed their stances because of the FabLab@School.dk project. Our lack of ability to show a statistically significant increase in the number of students taking a designerly stance towards inquiry highlights that such a stance and thus design literacy does not appear of its own accord when digital fabrication technologies are introduced into the classroom. Rather, the development of design literacy seems to require long-term commitment to systematic work with complex problem solving scaffolded by an iterative design process model.

6. Student motivation in the FabLab

In the literature on digital fabrication in education, the motivational aspects have often been pointed to as a primary objective for implementing work with these technologies (see e.g. (Martinez & Stager, 2013)). In the survey reported here, we wanted to investigate if students in the formal educational settings of FabLab@School.dk would likewise evaluate work with digital fabrication in education favorably.

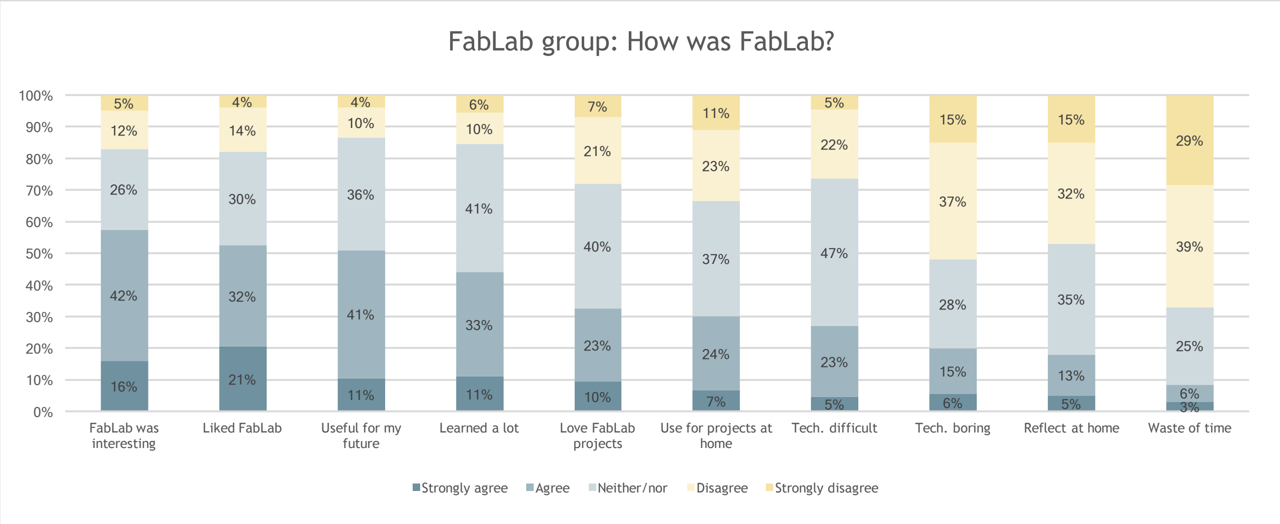

Figure 30: Responses from the FabLab group on the degree to which they agreed with statements about motivational aspects of the work with digital fabrication. Ordered by the sum of strongly agree and agree

Fifty-eight percent of the students from the FabLab group agreed (42 percent) or strongly agreed (16 percent) that they found the work in the schools' FabLab or makerspace interesting. Fifty-three percent agreed (32 percent) or strongly agreed (21 percent) that they had liked the work. Fifty-two percent of the FabLab students agreed (41 percent) or strongly agreed (11 percent) that the work with digital fabrication technologies in school would be useful for them in the future. Forty-four percent agreed (33 percent) or strongly agreed (11 percent) that they learned a lot from working in their school's FabLab or makerspace. Further, 33 percent of the students did to some extent agree that they loved doing projects with digital fabrication technologies (23 percent agreed, 10 percent strongly agreed). Thus, on average, students from the FabLab group found work with digital fabrication interesting (3.5) and useful (3.4). They liked (3.5) and even loved (3.1) projects in the FabLab or makerspace, and according to the students, they learned a lot (3.3).[4]

On average, the students reported that they did not find FabLab to be a waste of time (2.2) and they did not find the technologies boring (2.6). They did not report that they reflected on what they learned about digital fabrication technologies when they were at home (2.6), and they did not on average report that

[4] In order to calculate an average, the categories were assigned values which ranged from 1 (Strongly disagree) to 5 (Strongly agree). Such calculations entail the assumption that there are equal intervals between the different points on the scale. The mid-point of the scale is 3.0 and averages above 3.0 thus mean that students on average agree.

they would like to use the technologies for projects outside school (2.9), though 31 percent agreed or strongly agreed that they would. Approximately an equal number of students to some extent agreed (28 percent) or disagreed (27 percent) that the technologies were difficult. Overall, students from the FabLab group had positive experiences with working with digital fabrication and they found the work relevant. As with most of the other questions, however, there were noticeable differences between the school groups.

6.1. Comparing school groups on student motivation

Figure 31 compares student experiences with digital fabrication between the four groups of schools within the FabLab group.

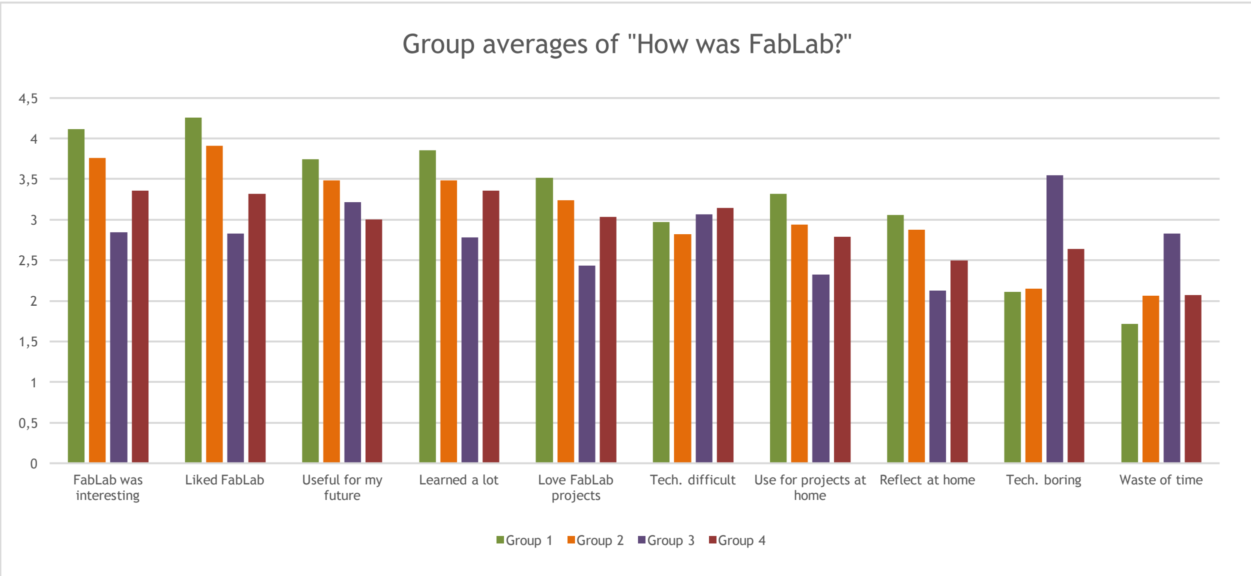

Figure 31: Group averages of answers on to which degree students from the groups agreed with the statements. Averages are calculated by assigning values of 1 (Strongly disagree) to 5 (Strongly agree). This entails the assumption, that intervals between the different categories are equal. Ordered by averages for the entire FabLab group.

As shown in Figure 31, students from group one and two were very positive about their experiences with digital fabrication in school. No students from group two and only 6 percent of the students in group one disagreed or strongly disagreed with liking the work in the FabLab or makerspace at their school, while only 3 and 6 percent from group one disagreed or strongly disagreed respectively with the statement "I learned a lot in FabLab/makerspace" (Not depicted here). Group one really stood out in the extreme answer categories: 49 percent of the students strongly agreed with liking being in their school's FabLab/makerspace, and 51 percent strongly disagreed that this was boring.

Comparing the average scores given by students from the various groups, the picture of students in groups one and two as the most positive is confirmed. On average, students from these two groups reported that they found being in their school's FabLab/makerspace interesting (4.1 and 3.8 respectively), that they liked being in the FabLab/makerspace (4.3 and 3.9), that what they learned about digital fabrication technologies would be useful for their futures (3.7 and 3.5), that they learned a lot in the

FabLab/makerspace (3.9 and 3.5), and that they loved doing projects with digital fabrication technologies (3.5 and 3.2).[5] The least motivated students were those in group three. These students on average did find the technologies useful for their futures (3.2), but they did not find FabLab/makerspace interesting (2.8), they did not on average like being in their school's FabLab/makerspace (2.8), they did not find they had learned a lot (2.8), and they did not love projects with digital fabrication technologies (2.4). They did, however, find the technologies boring (3.5).

In sum, the students from groups one and two were the most positive about their work with digital fabrication. Again, group one stood out. Students from this group were the most motivated with regard to their work with digital fabrication in school. Students from group three on the other hand stood out as the least motivated. These students were also the ones, who had to the least degree worked with real-world problems, and whose work had to the least degree been structured around the AU design process model. While the degree to which such work was structured by a design model could correlate to student motivation, more research is needed in order confirm or reject this hypothesis.

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[5] As before, in order to calculate an average, the categories were assigned values which ranged from 1 (Strongly disagree) to 5 (Strongly agree). Such calculations entail the assumption that there are equal intervals between the different points on the scale. The mid-point of the scale is 3.0 and averages above 3.0 thus mean that students on average agree.

7. Conclusion

In this report, we discuss a range of survey items, developed to gauge students' abilities to use, master and understand digital technologies, as well as their abilities to think and act innovatively with technology on societal challenges. In the report, we compare a group of students, who have worked with digital fabrication technologies as part of the FabLab@School.dk project in the period from 2014 to 2016 (FabLab group) with a group of students, who have not been a part of the project (control group), as well as to responses from our 2014 survey. Findings from these comparisons are discussed in section 7.1. One main finding was that there were large variations between schools within the FabLab group across a range of items discussed below. These variations have been investigated through comparisons of groups of schools within the FabLab group. Based on group interviews with students from eight FabLab schools, we divided these schools into four groups characterized by their answers within four categories of (1) the number of technologies applied from the teacher's and school's repertoire, (2) the degree to which the work with digital fabrication technologies had been framed as explorative design processes, (3) the degree to which the students had worked systematically with complex problem-solving, and (4) the degree to which the work with digital fabrication technologies was seen as an integrated part of school work in general. Findings from comparisons between groups of schools within the FabLab group are discussed in section 7.2.

7.1. FabLab group, control group, and the 2014 survey

As a group, the FabLab students had been exposed to more technologies than the control students and had more experience in using them to work on their own ideas. From the data (see Figure 3) it was clear that students in the FabLab group had on average been exposed to more digital fabrication technologies (4.4 technologies per student on average) than those in the control group (average: 2.2). Further, as shown in the figure, the FabLab students had tried to work with their own ideas with a wider range of technologies (see Figure 10). This suggests that FabLab students had more experiences in working with their own ideas using digital fabrication technologies than students from the control group. However, students from the control group had worked with more digital fabrication technologies than expected (see Figure 5. According to their answers (see Figure 20), students from the FabLab group had learned to use a larger number of digital fabrication technologies in school than students from the control group had (see Figure 21). The control group students to a greater extent had to gain experience with digital fabrication in out-of-school contexts, but their answers demonstrate that advanced technologies such as 3D printers and robotics are becoming more common both in schools and in society in general.

Compared to the 2014 group (see Figure 17), the FabLab group had significantly higher self-perceived knowledge of all digital fabrication technologies except electronics and soldering. This suggests that students in the FabLab@School.dk project on average perceived of themselves as more knowledgeable about digital fabrication technologies than they would have at the beginning of the project.

Stances towards inquiry are difficult to change. In the FabLab@School.dk project, inquiry, field studies, and a designerly stance towards inquiry had been emphasized. However, there was no statistically significant difference between the 2014, control and FabLab groups in regard to students' stances towards inquiry, and this highlights that a designerly stance towards inquiry is not easily acquired and require a long-term commitment to working with real-world problems.

7.2. Comparing groups of schools

In this section, we present Figure 32 to compare groups of schools across a range of the topics discussed in the present report. Here, the number of technologies used by students in school groups and the number of technologies used to work with students' own ideas are depicted in the same chart as combined scores on items of motivation, knowledge of technologies and the design process model, and students' self-perceived outcomes. It is important to note, however, that the various items are not all measured on the same scale. The number of technologies is measured as a simple count, while knowledge of the design process model and digital fabrication technologies as well as students' outcomes are measured on 6-point Likert scales with a median of 3.5. The motivational score is measured on a 5-point Likert scale with a median of 3.

7.2.1. Calculations of the combined scores

Scores in Figure 32 below were calculated as follows. The number of total technologies used by a school group and the number of technologies used to work on own ideas are average counts of technologies within the group. The scores for knowledge of the design process model and the scores for knowledge of digital fabrication technologies are simple averages across included items and students in the group. In order to create a single score for student motivation, we averaged scores on the first five items and the inverted scores on the last two items in Figure 31. The last three scores in Figure 32 are all made from data depicted in Figure 25: Creativity with technology is the average of scores on "To be creative with technology", "To Imagine change with technology", and "How new technology, ideas, and things are created." Critical reflection with technology is the average of "To reflect critically on technology" and "How technologies affect our lives." The score for complex problems is made of the same values as "To solve complex challenges."

Figure 32: Combined scores for different parts of the questionnaire. Scores are averages of scores reported above. The design process model and Technologies scores are the group average scores on all items within their respective sections. The other scores are made up of only some of the scores from their respective sections. The different items are calculated differently and with different scales, and therefore they cannot be compared directly.

As depicted on Figure 32, there were large variations within the FabLab group in regard to the number of technologies encountered, design process structuring, student motivation, and the students' self-perceived knowledge and outcomes. There was no centralized strategy in the FabLab@School.dk project in regard to how many technologies to use, which technologies to use, and how to implement the technologies. Rather, the implementation was left to the individual teachers' preferences and competences, as well as the availability of technologies at each school. We expect this to be the main factor accounting for the large amount of variation. The variations between groups of schools within the FabLab group were:

- There was a large degree of between-group variation on the average number of technologies students had worked with. On average, students from group 1 reported that they had worked with 5.8 of the digital fabrication technologies, students from group 2 that they had worked with 4.9, students from group 3 that they had worked with 4.5, and students from group 4 that they had worked with 2.7 digital fabrication technologies. There were also large variations in which technologies students from the different groups reported having worked with. Further, there were large variations in the number of technologies students in the four groups had used to work with their own ideas. Here, school group 2 stood out with the highest average number of technologies used in this way (3.6) – to a large degree helped by two outliers claiming to have used all or nearly all technologies to work on their own idea. The other groups of schools followed the trend from the total number of technologies used, in that students from group 1 had used the highest number of technologies to work with their own ideas (3.2), followed by group 3 (2.3), and group 4 (1.2).
- There were large between-group variations in the *use of AU's design process model* and in the students' self-perceived knowledge of its parts. All interventions, workshops, and teacher training done by

Aarhus University's Child–Computer Interaction Group as part of the FabLab@School project were centered on the design process model developed here. Students from group 1 stood out by on average evaluating their knowledge of the parts of the design process model highest of all the groups. Students from group three on average evaluated their knowledge lower than students from the other groups.

- Additionally, there was a large between-group variation in *student motivation* and in their perception of their experiences working with digital fabrication technologies. Students from group one and two were the most positive in regard to their work with digital fabrication. Again, group one stood out: group one students on average evaluated their work with digital fabrication in school more positively than any of the other groups. Group three students evaluated their experiences with digital fabrication negatively compared to the other groups.
- There was a large between-group variation in students' *knowledge of digital fabrication technologies* at the end of the two-year project period. As stated above, students from the FabLab@School.dk project had on average evaluated their knowledge of digital fabrication technologies more highly than the average of students in the 2014 survey. There was, however, a large variation between the responses from groups of schools. According to the responses, students from group 1 were on average more knowledgeable about the surveyed digital fabrication technologies than the average of students from group 2, who were more knowledgeable than the average of students from group 3, who were in turn on average more knowledgeable than the average of students in group four.
- There was a large between-group variation in the *learning outcomes* of working with digital fabrication technologies. The general trend with regard to the different types of learning outcomes was that students from groups 1 and 2 evaluated their learning outcomes more highly than students from groups 3 and 4. Especially students from group 1 perceived that they had had large gains in their abilities to produce with digital fabrication technology (thinking and acting innovatively with technology), to critically reflect on the use of technology, and to solve complex problems.

The data suggests a correspondence between number of technologies, use of a design process model, motivation, and learning outcomes: looking at the use of the design process model as evidenced by student responses to questions on whether they had used the model and the degree to which they knew its different parts, we find it plausible to suggest that in schools where the design process had been structured and scaffolded by the use of a design process model, students came to feel more secure about taking on complex problems. However, more research is needed in order to substantiate this claim. In the project reported here, we have introduced an experiment into the existing public school system, which is currently directed by a long list of common goals. It will be interesting to follow the continued efforts to create a place for design-based work with complex problems in digital fabrication within this system.

We did see small steps leading in the direction of design literacy, but the results highlight that it is challenging for both teachers and students to work towards this goal, which is not yet clearly defined. In our interpretation, the data suggests that scaffolding and structuring the work with digital fabrication in schools around a design process model like the one developed within the FabLab@School.dk project furthers the development of design literacy. However, with the large variation between schools and in the absence of central strategies and goals, it is very much up to chance what education in digital fabrication and design processes the students get.

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Appendix A: Full translations of questions

Heading	Question	Categories	Abbreviated question
	PERSONAL INFORMATION		
First, we would like to know a little about you and your school	How old are you?	Open question	Age
	What is the name of your school?	Open question	School
	What is your gender?	Boy	Gender
		Girl	
	Which grade are you in?	6, 7, 8, or 9	Grade level
	TECHNOLOGIES		
Here, we ask you about specific technologies that you might have worked with in school	In what way have you worked with the following technologies		
	3D printer	I have never worked with this technology	3D printer
		I have followed instruction to make something with this technolgy	
		I have used this technology to work on my own idea	
	Laser cutter	(same as above)	Laser cutter
	Vinyl cutter	(same as above)	Vinyl cutter
	MakeyMakey	(same as above)	MakeyMakey
	Arduino	(same as above)	Arduino
	LittleBits	(same as above)	LittleBits
	LilyPad	(same as above)	LilyPad
	Programmable robots (e.g. LEGO Mindstorms)	(same as above)	Robots (prog.)
	Electronics and soldering (LEDs and resistors)	(same as above)	Electronics

	Text-based programming (e.g. HTML, Processing, Arduino, Sonic Pi, or Python)	(same as above)	Textbased prog.
	Blockbased or visual programming (e.g. LEGO Mindstorms, Scratch, ArduBlock, or Weedoo)	(same as above)	Blockbased/visual prog.
	Other digital fabrication technologies	(same as above)	Other
	List the technologies, you have worked with. Describe what the technologies were used for.	Open question	What other technologies have you work with, and how?
How familiar are you with the following technologies?	Evaluate yourself on a scale of 1 (I know nothing about it) to 6 (I could teach others about it).		
	Computers/laptops	1, 2, 3, 4, 5, or 6	Computers
	Smartphones/tablets/iPads	1, 2, 3, 4, 5, or 6	Smartphones/tablets
	Laser cutter/CNC router	1, 2, 3, 4, 5, or 6	Laser cutter/CNC
	Vinyl cutter	1, 2, 3, 4, 5, or 6	Vinyl cutter
	3D printer	1, 2, 3, 4, 5, or 6	3D printer
	Building electronic devices or simple machines from scratch	1, 2, 3, 4, 5, or 6	Building electronic devices
	Microcontroller boards (e.g. MakeyMakey og Arduino)	1, 2, 3, 4, 5, or 6	Microcontroller boards
	Building programmable robots (e.g. Lego Mindstorms)	1, 2, 3, 4, 5, or 6	Robots (prog.)
	Electronis and soldering (LEDs and resistors)	1, 2, 3, 4, 5, or 6	Electronics
	TExt-based programming (e.g. HTML, Processing, Arduino, Sonic Pi, or Python)	1, 2, 3, 4, 5, or 6	Textbased prog.
	Blockbased or visual programming (e.g. LEGO Mindstorms, Scratch, ArduBlock, or Weedoo)	1, 2, 3, 4, 5, or 6	Blockbased/visual prog.
	Where did you learn this?		
	Laser cutters or CNC routers	Primarily in school	Laser cutter/CNC
		Primarily at home	
		Have not learned	

	Vinyl cutter	(same as above)	Vinyl cutter
	3D printer	(same as above)	3D printer
	Building electronic devices or simple machines from scratch	(same as above)	Building electronic devices
	Microcontroller boards (e.g. MakeyMakey og Arduino)	(same as above)	Microcontroller boards
	Building programmable robots (e.g. Lego Mindstorms)	(same as above)	Robots (prog.)
	Electronics and soldering (LEDs and resistors)	(same as above)	Electronics
	TExt-based programming (e.g. HTML, Processing, Arduino, Sonic Pi, or Python)	(same as above)	Textbased prog.
	Blockbased or visual programming (e.g. LEGO Mindstorms, Scratch, ArduBlock, or Weedoo)	(same as above)	Blockbased/visual prog.
Has worked with digital fabrication in school	Have you ever worked with digital fabrication technologies, for example in a FabLab or workshop, in school? Digital fabrication technology can for example be MakeyMakey, Arduino, vinyl cutter, and 3-D printer.	Yes / no	
What did you make, and with what technology?	Briefly describe what you made, which technology you used, and what you used the technology to do?		
	1. project	open question	
	2. project	open question	
Here, we ask you how you liked working with digital fabrication technologies in school. In som schools, there is a space called a FabLab or a Makerspace, where you can	How did you like working with digital fabrication in school/FabLab?		

work with these technologies			
	The technologies were difficult	Strongly disagree	Tech. difficult
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	Working with the technologies was boring	(same as above)	Tech. boring
	I like being in the school's FabLab/Makerspace	(same as above)	Liked FabLab
	Being in the school's FabLab/Makerspace is interesting	(same as above)	FabLab is interesting
	Being in the school's FabLab/Makerspace is boring	(same as above)	Waste of time
	I want to use the technologies for my own projects out of school	(same as above)	Use for projects at home
	The things we learn about digital fabrication technologies will be useful for me in the future.	(same as above)	Useful for my future
	I love working on digital fabrication projects.	(same as above)	Love FabLab projects
	I learn a lot in the school's FabLab/makerspace	(same as above)	Learned alot
	When I am home, I think about what we learned about digital fabrication technologies	(same as above)	Reflect at home
To what extent do you agree? Use the scale of 1 to 6, where 1 means "Strongly disagree", while 6	Digital fabrication in school has		

means "Strongly agree"			
	taught me how to work creatively with technology	Strongly disagree	To be creative with tech.
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	taught me how to solve complex challenges	(same as above)	To solve complex challenges
	helped me relate to societal issues	(same as above)	To relate to societal challenges
	helped me to imagine how I can change things (e.g. with technology)	(same as above)	To imagine change w/ tech.
	helped me become better at cooperating with people with different backgroups and abilities	(same as above)	To cooperate in heterogeneous groups
	taught me how technology is affecting the way we live	(same as above)	How tech. Affects our lives
	taught me how new ideas, things, and technologies are created.	(same as above)	How new tech./ideas/things are created
	helped me reflect critically to my own and others' use of technology (e.g. are we spending too much time on Facebook?, are our pictures safe on Snapchat?, are we creating too much e-Waste?).	(same as above)	To reflect critically on tech.
	helped me to communicate with various people on the internet.	(same as above)	To communicate on the Internet
	taught to work systematically with assignments (e.g. in Physics, Chemistry, or Science)	(same as above)	To work systematically
	has heightened my interest in completing a degree in higher education.	(same as above)	Interest in higher education

	has heightened my interest in wanting a creative or craftmanship education.	(same as above)	Interest in Crafts or creative education
	heightened my interest in starting my own company.	(same as above)	Interest in entrepreneurship
DESIGN AND CREATIVITY			
The next questions concern having novel ideas, working creatively, and creating new things with technolgy	How you ever worked with this design process model in your school?	Yes / no / don´t know	
How familiar are you with the various parts of the Design Process Model?	Evaluate yourself on a scale of 1 (I know nothing about it) to 6 (I could teach other about it).		
	Design brief	1, 2, 3, 4, 5, or 6	Design brief
	Field studies	1, 2, 3, 4, 5, or 6	Field studies
	Ideation	1, 2, 3, 4, 5, or 6	Ideation
	Fabrication	1, 2, 3, 4, 5, or 6	Fabrication
	Argumentation	1, 2, 3, 4, 5, or 6	Argumentation
	Reflection	1, 2, 3, 4, 5, or 6	Reflection
	How you ever had an idea for a new product or an invention?	Yes/no	How you ever had an idea for a product or an invention?
	Describe your idea (briefly)	Open question	Describe your idea (briefly)
	Did you create or build your idea?	Yes/no	Did you create your idea?
Design task: The challenge of the care home	In the beginning of the year 2014, 9 grandparents disappeared from their care home because of their loss of memory (dementia). The problem for the care home is to create security for the elderly without taking away their freedom.	Open question	If you were asked to solve this problem, what would you do?

	If you were asked to solve this problem, what would you do?		
How would you find the right solution to the problem of elderly demented disappearing?	Which parts of the process would be most important to you? Choose a number from 1 to 6 (1 = not important at all, 6 = very important)		
	I would create a detailed plan for the entire project	1, 2, 3, 4, 5, or 6	Create a detailed plan
	I would wait for a good idea to materialize	1, 2, 3, 4, 5, or 6	Wait for good idea
	I will visit a care home to study the problem further	1, 2, 3, 4, 5, or 6	Study nursing homes
	I would find out, how they handle this problem in other countries	1, 2, 3, 4, 5, or 6	Study other countries
	I will sketch possible solutions on paper	1, 2, 3, 4, 5, or 6	Sketch on paper
	I will build my idea using cardboard	1, 2, 3, 4, 5, or 6	Build cardboard mock-up
	I will test my cardboard model in a care home	1, 2, 3, 4, 5, or 6	Test cardboard mock-up
	I will repeat the tests with a new sketch or cardboard model	1, 2, 3, 4, 5, or 6	Iterate on mock-up or sketch
	I will test my solution together with elderly at the care home	1, 2, 3, 4, 5, or 6	Test solution with elderly
	I will arrange a meeting with staff and relatives to discuss my solution	1, 2, 3, 4, 5, or 6	Meet w/ staff/relatives
	I will make sure everybody agreed on the solution	1, 2, 3, 4, 5, or 6	All should agree
	I will use disagreements between individuals/groups to develop new ideas	1, 2, 3, 4, 5, or 6	Use disagreement fruitfully

	I will patent my idea	1, 2, 3, 4, 5, or 6	Patent the idea
	I will start a company to market my solution and make money	1, 2, 3, 4, 5, or 6	Market solution/make money
	As soon as my solution is finished, I will stop working on the the problem	1, 2, 3, 4, 5, or 6	Stop working when finished
	I will use knowledge gained in this project for future projects	1, 2, 3, 4, 5, or 6	Transfer knowledge to future projects
	Other things you would do? Describe them here.	Open question	Other
HACKING, DATA, AND TECHNOLOGY			
Here, we ask about your relationship to hacking and reparation of technology in your everyday life.	To what extent do you agree…		What is your relationship with technology?
	As long as they function properly, I don't care how my digital devices work	Strongly disagree	Don´t care how they work, as long as they work
		Disagree	
		Neither/nor	
		Agree	
		Strongly agree	
	I am interested in knowing how my devices work, and I often improve them	(same as above)	I want to know how they work and how to improve them
	When I notice something broken, I immediately think of a way to fix it	(same as above)	When things are broken, I think of ways to repair
	I know what is inside a phone and how it works	(same as above)	I know what is inside a phone/how it works
What do you do, if something doesn't work on e.g. Your computer or phone?	Choose three options		What do you do, if a device malfunctions?
	Call a friend	[check box]	Call a friend
	Read a manual	[check box]	Read a manual
	Ask one of my parents	[check box]	Ask a parent
	Call technical support	[check box]	Call technical support

	Search for (solutions to) the problem on the internet	[check box]	Search the Internet
	Seach for help on specific websites	[check box]	Search specific/relevant sites
	Start a thread/discussion - e.g. In a forum	[check box]	Start a thread/discussion
	Tinker with known commands, settings, etc.	[check box]	Tinker
	I do not know	[check box]	Do not know
	Other	[check box]	Other
	Please desribe…		Describe…
	Have you ever taken your phone or other digital devices apart?	Yes / no/do not know	How you ever taken your phone or other devices apart?
	Why did you open it? Was it e.g. To fix or improve something?	Open question	Why?
	Why Not?		
	Why would I?		
	I do not know how	[check box]	Why would I?
	I would void the warranty	[check box]	Does not know how
	I do not know	[check box]	Would void the warranty
	Other	[check box]	Do not know
	Please describe	[check box]	Other
			Describe
	To what extent do you agree with these statements about technology and data?		To what extent do you agree?
	Technology, data, and information should be open and available to all	Strongly disagree	Tech./data/info. should be free/open to everyone
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	National agencies should store everyones personal data and information	(same as above)	National agencies should store personal data

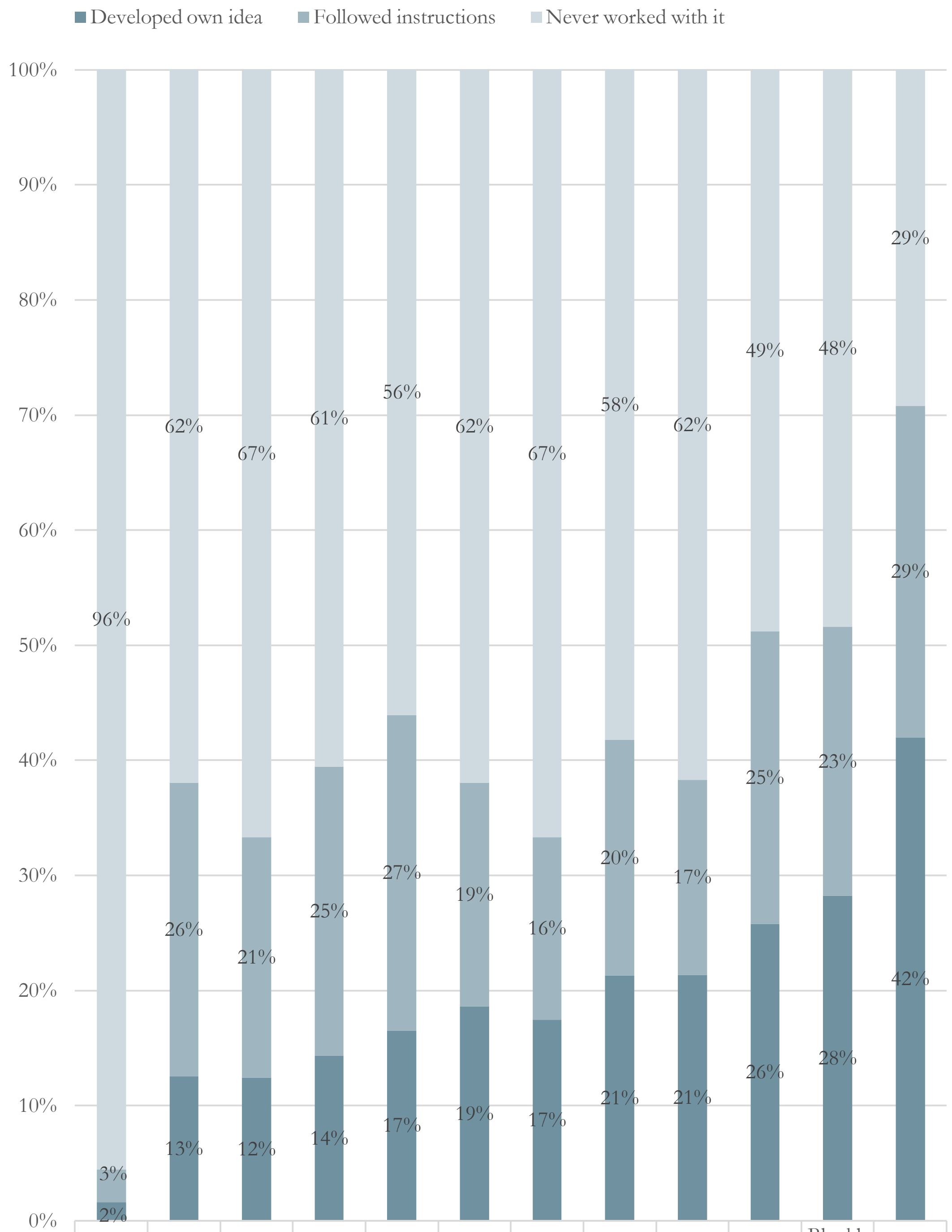
	It is important to me, who owns my data and informations, e.g. Photos and music	(same as above)	Important who owns data
	Hacking is only something criminals do on the internet	(same as above)	Hacking is done by criminals
	Hacking is something everyone does	(same as above)	Hacking is done by everyone
	Technology gives me freedom to express my interests	(same as above)	Technology gives me freedom to express my interests
	I can imagine how technology can be combined with other materials (e.g. Fabric, wood, or paper)	(same as above)	Technology can be combined with other materials
	Technology allows me to understand new contexts and opportunities	(same as above)	Technology allows me to understand new contexts and opportunities
YOUR FUTURE			
In the end, we would like to know if you would be interested in a career in technolgy, design, science, or in starting your own business. Further, we about the number of books in your home.	Here, we ask about your thoughts on the future. To what extent do you agree?		What are your thoughts on the future?
	I am interested in a career in technology and design	Strongly disagree	Future in digital design
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	I am interested in a career in engineering or science	(same as above)	Future in engineering/science
	I am interested in starting my own business	(same as above)	Start my own business

	Approximately how many books are there where you live? (You should not count magazines, newspapers, or school books)		Books at home
	0-10	[check box]	
	11-25	[check box]	
	26-100	[check box]	
	101-200	[check box]	
	More than 200	[check box]	

Appendix B: Responses from the FabLab group

This appendix features tables charts of the FabLab group's responses on quantitative items in the questionnaire.

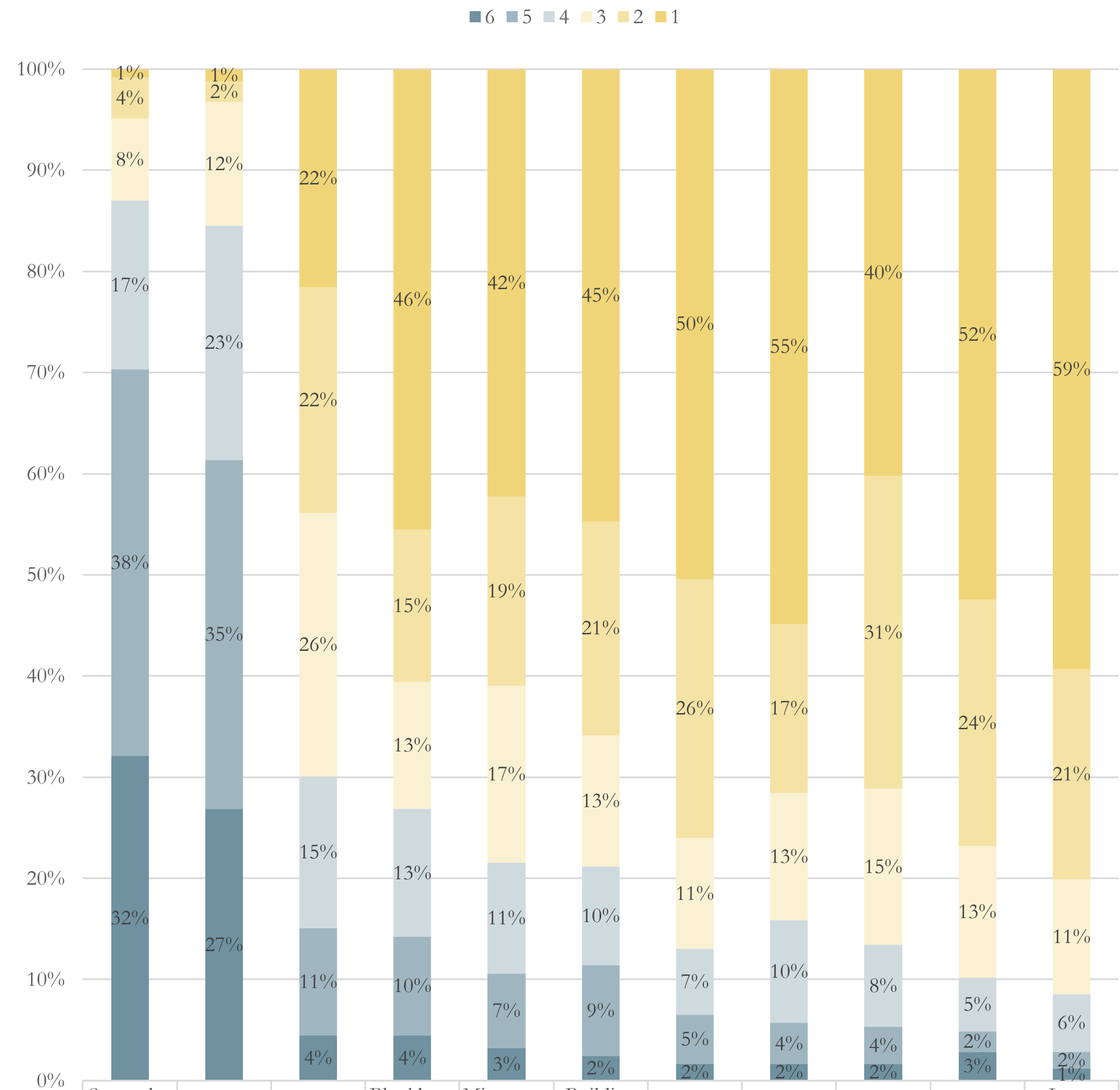
B.I: How did you work with the following technologies?



	LilyPad	Electronics	Laser cutter	Other	Textbased prog.	Arduino	LittleBits	Vinyl cutter	Makey Makey	Robots (prog.)	Blockbased/visual prog.	3D printer
Never worked with it	236	153	166	152	139	153	164	145	153	121	120	73
Followed instructions	7	63	52	63	68	48	39	51	42	63	58	72
Developed own idea	4	31	31	36	41	46	43	53	53	64	70	105

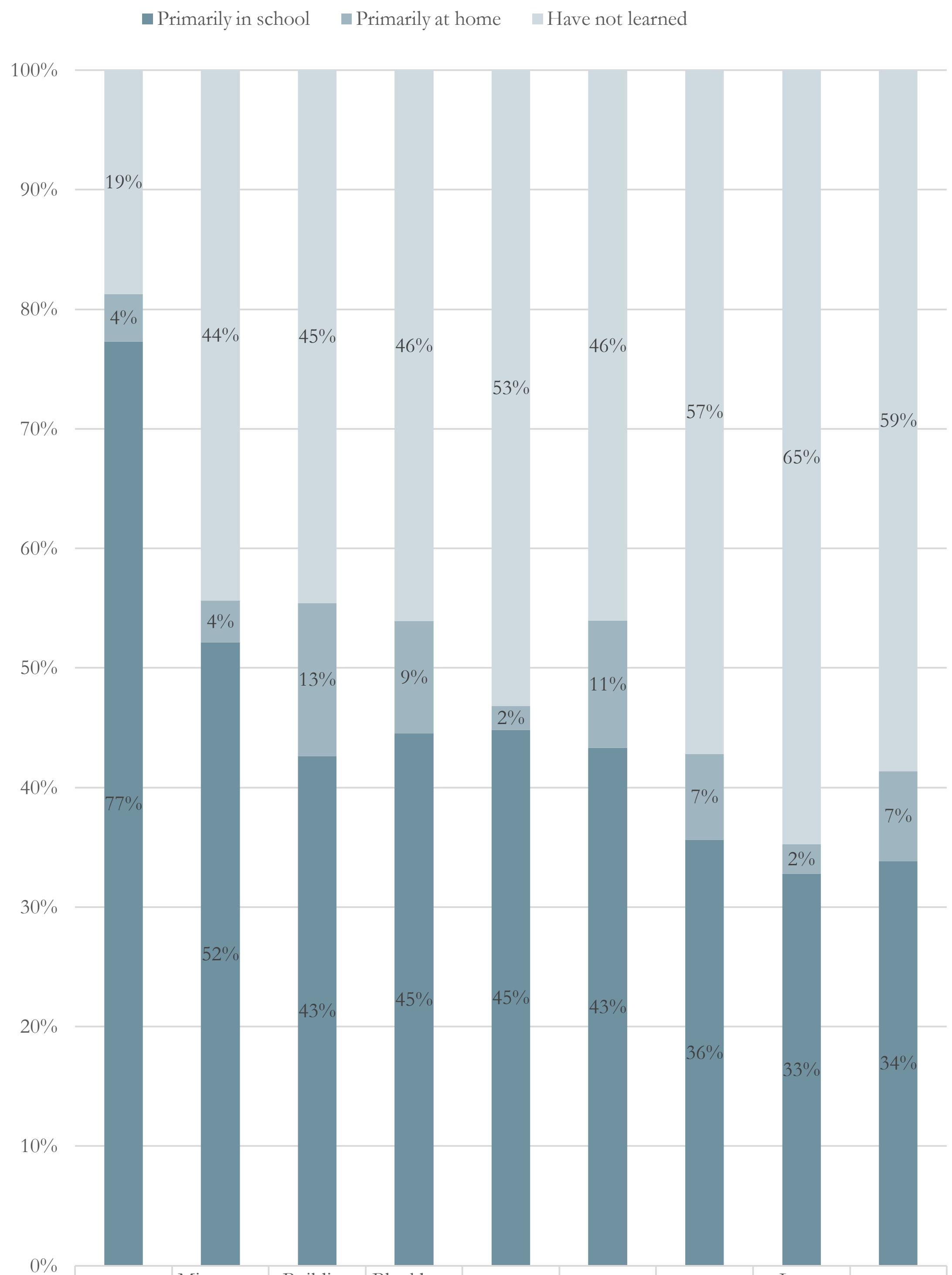
B.II: How familiar are you with these technologies?

Evaluate yourself on a scale from 1 to 6, where 1 is "I know nothing about it" and 6 is "I could teach others about it".



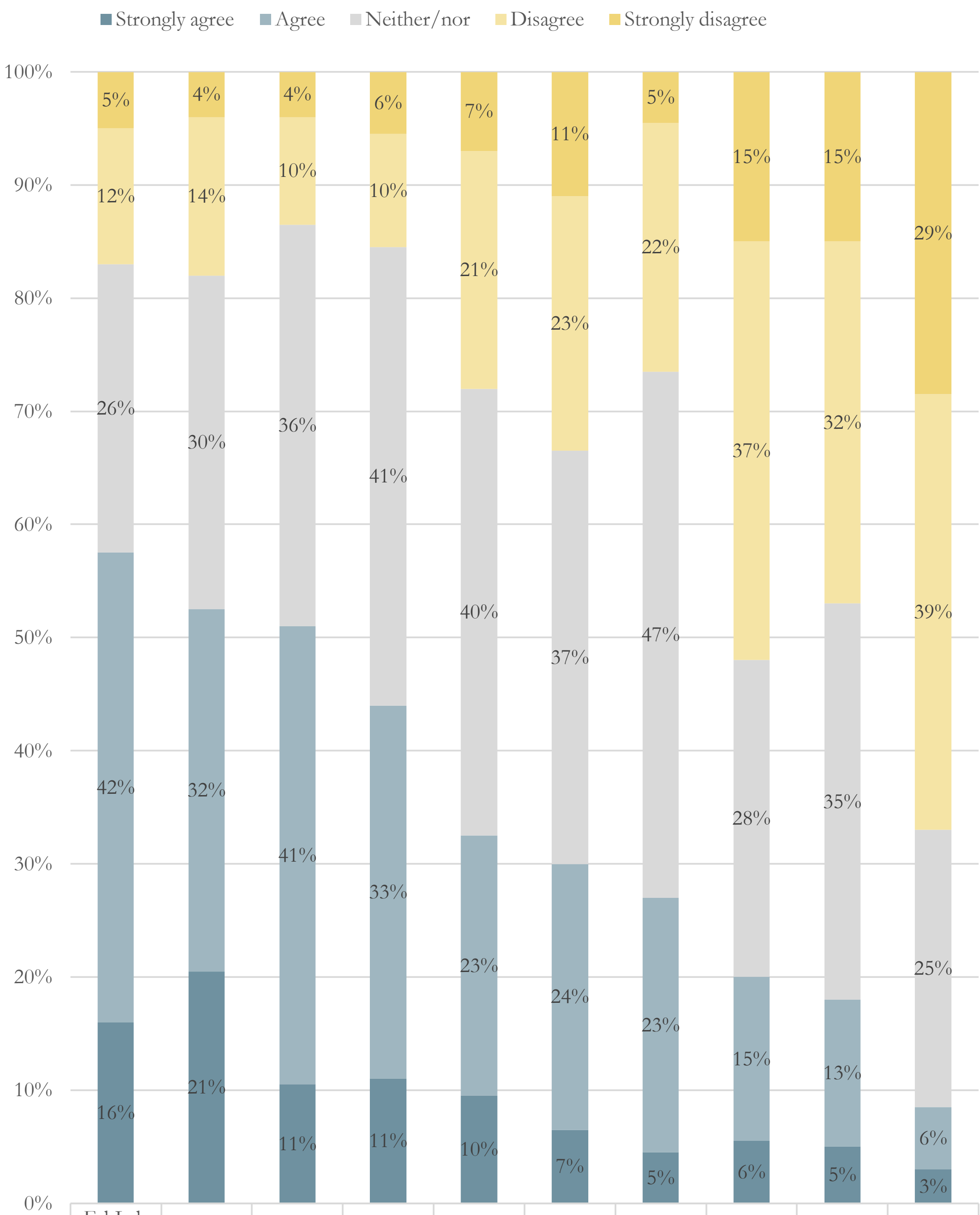
	Smartphones/tablets	Computers	3D printer	Blockbased/visual prog.	Microcontroller boards	Building electronic devices	Textbased prog.	Vinyl cutter	Robots (prog.)	Electronics	Laser cutter/CNC
1	2	3	53	112	104	110	124	135	99	129	146
2	10	5	55	37	46	52	63	41	76	60	51
3	20	30	64	31	43	32	27	31	38	32	28
4	41	57	37	31	27	24	16	25	20	13	14
5	94	85	26	24	18	22	12	10	9	5	4
6	79	66	11	11	8	6	4	4	4	7	3

B.III: Where did you learn to use these?



	3D printer	Microcontroller boards	Building electronic devices	Blockbased/visual prog.	Vinyl cutter	Robots (prog.)	Textbased prog.	Laser cutter/CNC	Electronics
Have not learned	47	114	115	118	133	117	143	160	149
Primarily at home	10	9	33	24	5	27	18	6	19
Primarily in school	194	134	110	114	112	110	89	81	86

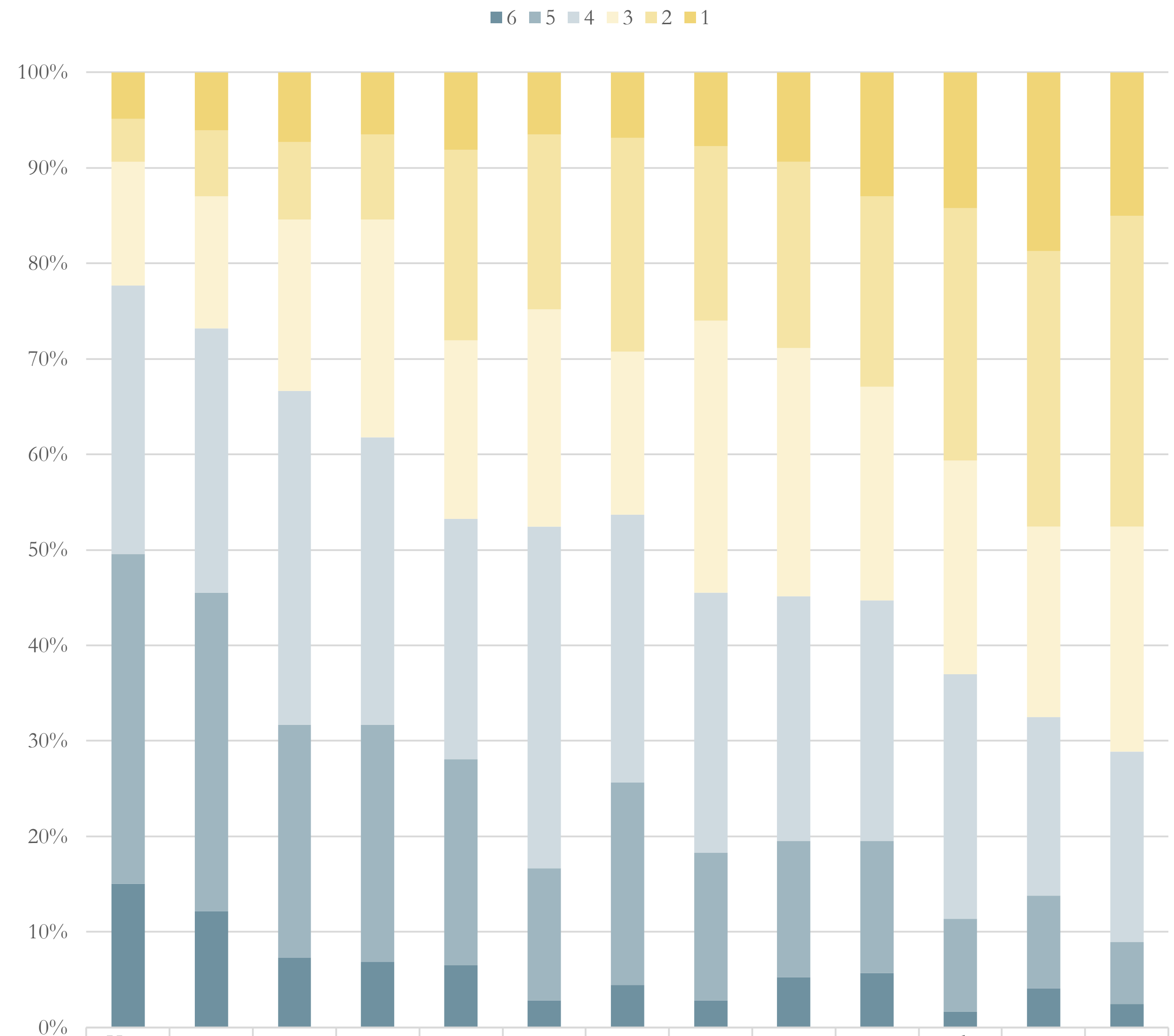
B.IV: How was working with digital fabrication in school/FabLab



	FabLab was interesting	Liked FabLab	Useful for my future	Learned a lot	Love FabLab projects	Use for projects at home	Tech. difficult	Tech. boring	Reflect at home	Waste of time
Strongly disagree	10	8	8	11	14	22	9	30	30	57
Disagree	24	28	19	20	42	45	44	74	64	77
Neither/nor	51	59	71	81	79	73	93	56	70	49
Agree	83	64	81	66	46	47	45	29	26	11
Strongly agree	32	41	21	22	19	13	9	11	10	6

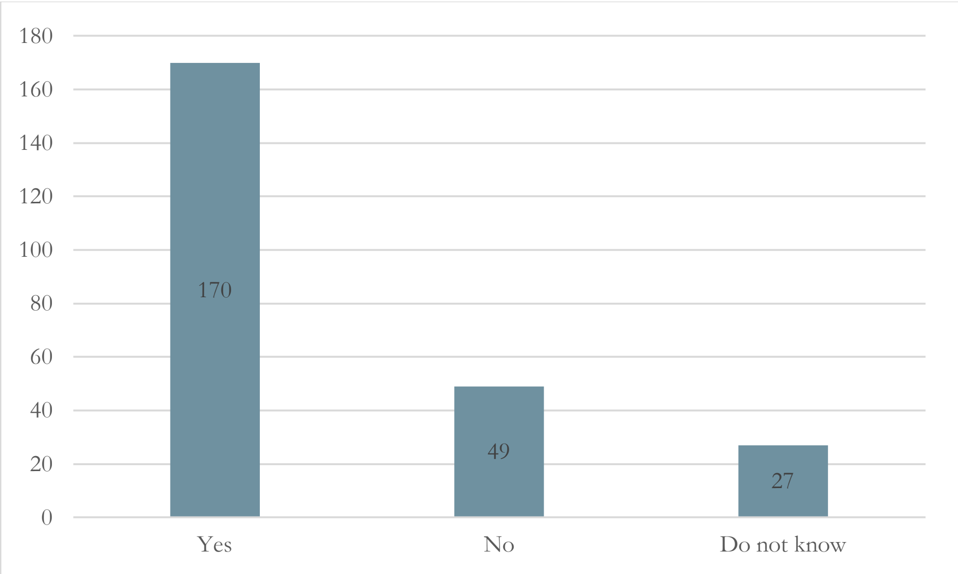
B.V: Learning outcomes

To which degree do you agree with the following statements? Work with digital fabrication in school has taught me…



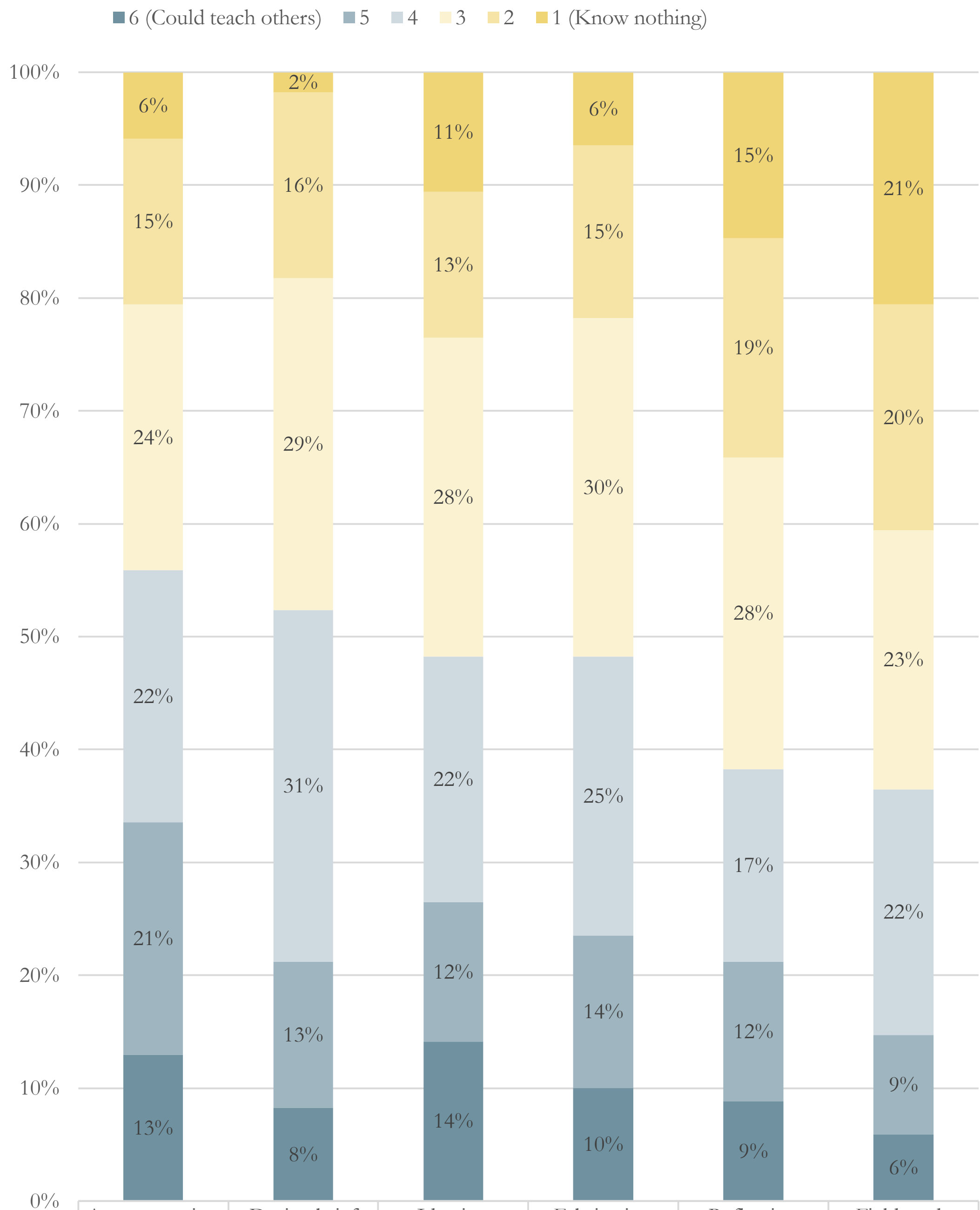
	How new tech./ ideas/ things are created	How tech. Affects our lives	To be creative with tech.	To imagine change w/ tech.	To reflect critically on tech.	To solve complex challenges	To cooperate in heterogeneous groups	To work systematically	To relate to societal challenges	to be interested in higher education	to be interested in crafts or creative education	To be interested in entrepreneurship	To communicate on the Internet
1	12	15	18	16	20	16	17	19	23	32	35	46	37
2	11	17	20	22	49	45	55	45	48	49	65	71	80
3	32	34	44	56	46	56	42	70	64	55	55	49	58
4	69	68	86	74	62	88	69	67	63	62	63	46	49
5	85	82	60	61	53	34	52	38	35	34	24	24	16
6	37	30	18	17	16	7	11	7	13	14	4	10	6

B.VI: Have you ever worked with this Design Process Model in school?



B.VII: How familiar are you with these parts of the Design Process Model?

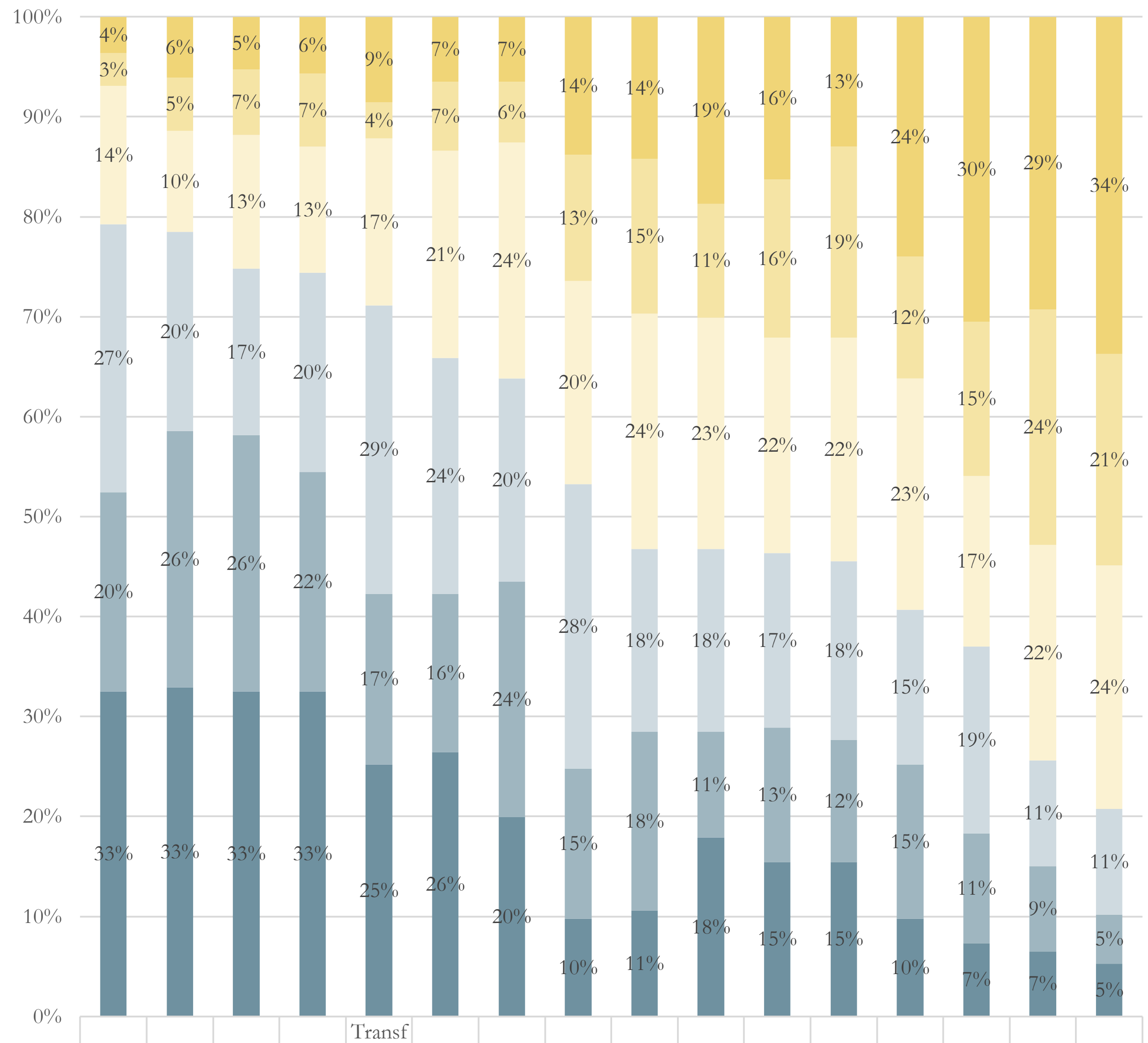
Evaluate yourself on a scale of 1 to 6, where 1 is “I know nothing about it” and 6 is “I could teach others about it”.



	Argumentation	Design brief	Ideation	Fabrication	Reflection	Field study
1 (Know nothing)	10	3	18	11	25	35
2	25	28	22	26	33	34
3	40	50	48	51	47	39
4	38	53	37	42	29	37
5	35	22	21	23	21	15
6 (Could teach others)	22	14	24	17	15	10

B.VIII: Which parts of the process would be most important to you?

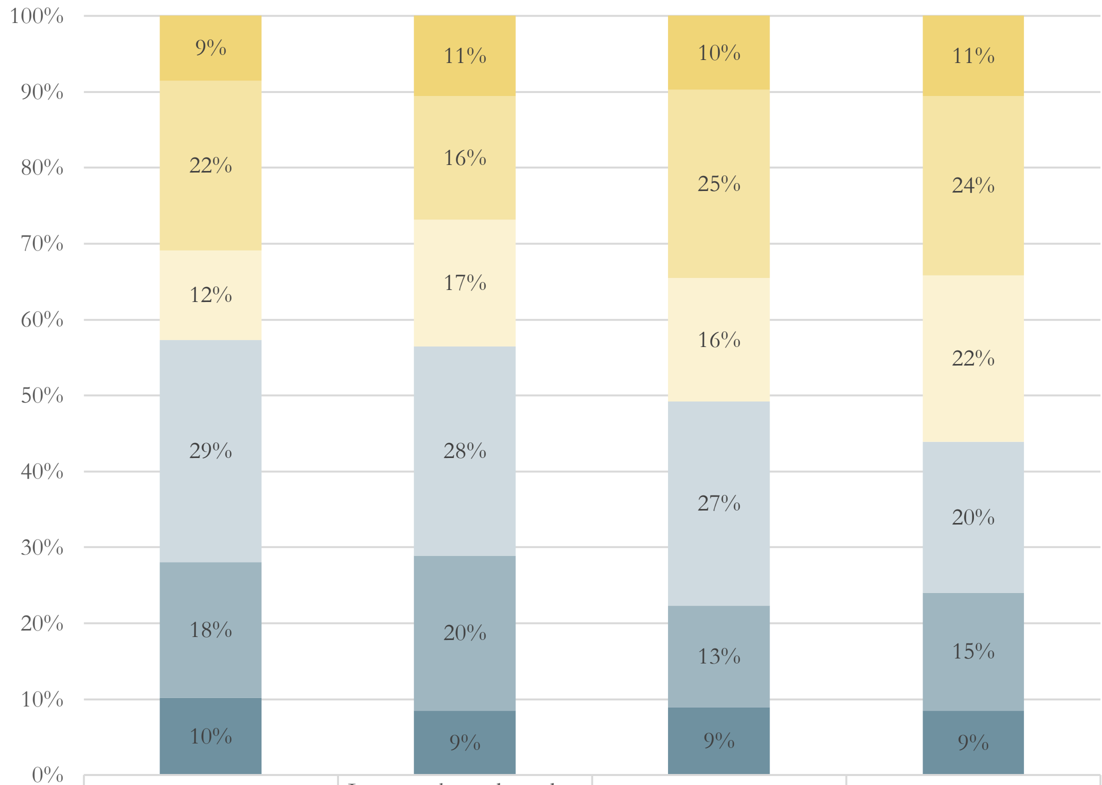
Choose a number between 1 and 6 (1 = not important at all, 6 = really important)



	All should agree	Meet w/ staff/relatives	Study nursing homes	Test solution with elderly	Transfer knowledge to future projects	Create a detailed plan	Use disagreement fruitfully	Study other countries	Sketch on paper	Patent the idea	Market solution/make money	Wait for good idea	Iterate on mock-up or sketch	Test cardboard mock-up	Stop working when finished	Build cardboard mock-up
1	9	15	13	14	21	16	16	34	35	46	40	32	59	75	72	83
2	8	13	16	18	9	17	15	31	38	28	39	47	30	38	58	52
3	34	25	33	31	41	51	58	50	58	57	53	55	57	42	53	60
4	66	49	41	49	71	58	50	70	45	45	43	44	38	46	26	26
5	49	63	63	54	42	39	58	37	44	26	33	30	38	27	21	12
6	80	81	80	80	62	65	49	24	26	44	38	38	24	18	16	13

B.IX: Relationship to hacking and reparation in everyday life

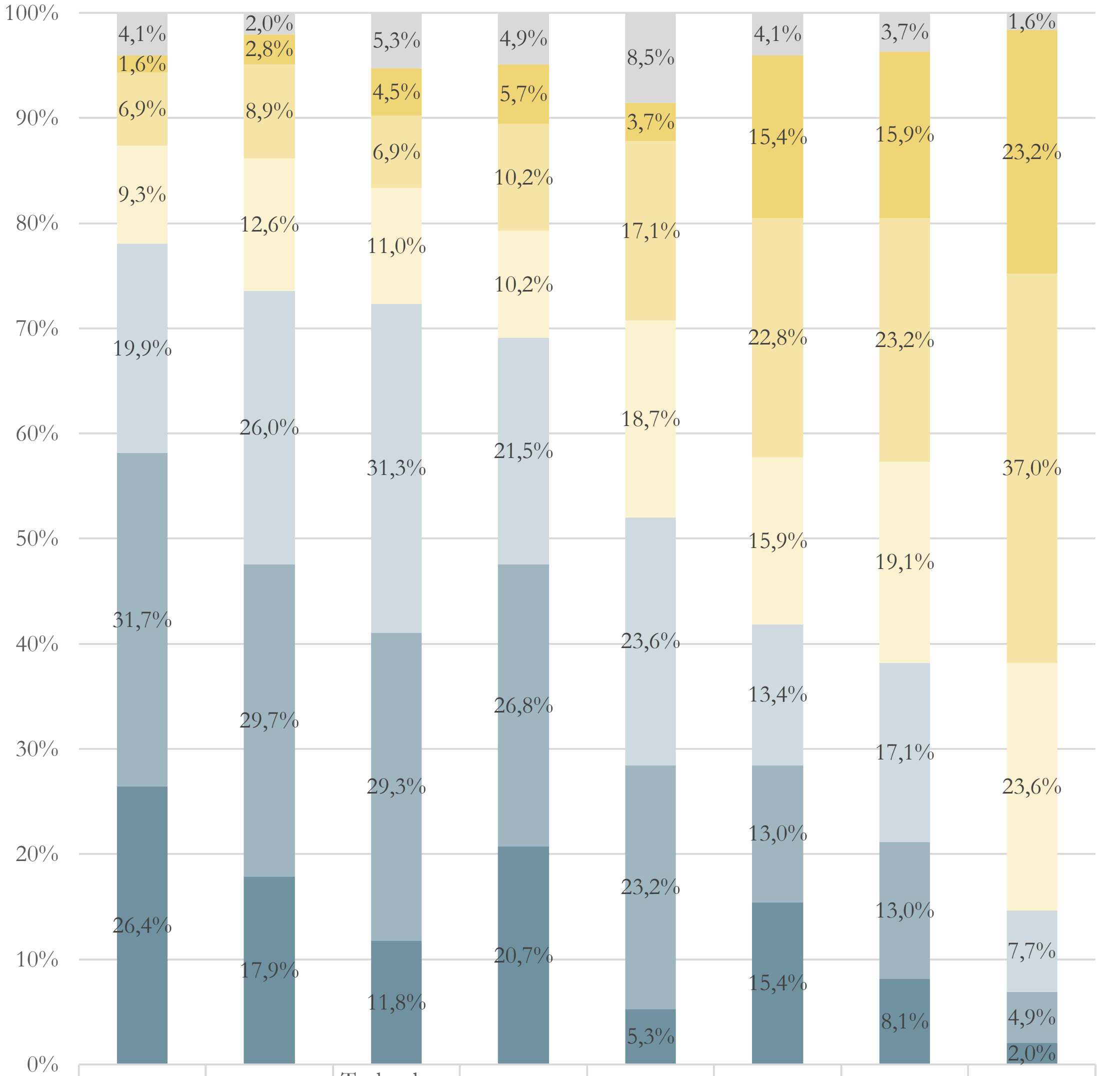
To what extent do you agree?...



	I know what is inside a phone/how it works	I want to know how they work and how to improve them	When things are broken, I think of ways to repair	Don´t how they work, as long as they work
Strongly disagree	21	26	24	26
Disagree	55	40	61	58
Slightly disagree	29	41	40	54
Slightly agree	72	68	66	49
Agree	44	50	33	38
Strongly agree	25	21	22	21

B.X: Technology and data

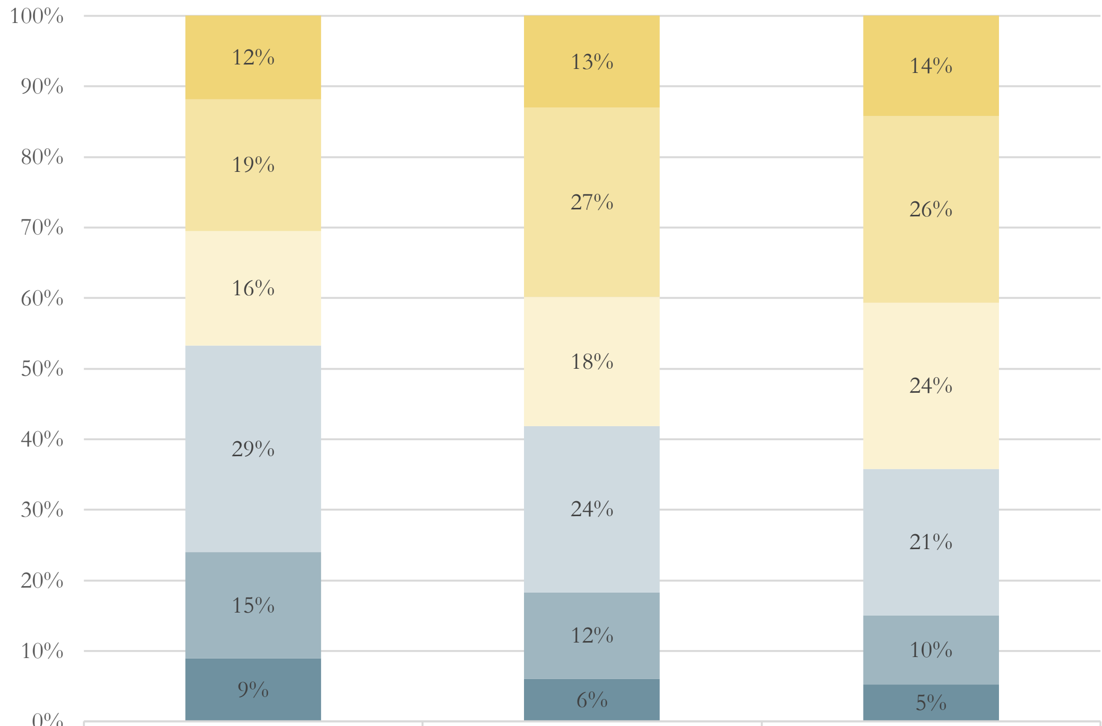
To what extent do you agree with these statements?



	Important who owns data	Technology gives me freedom to express my interests	Technology allows me to understand new contexts and opportunities	Tech./data/ info. should be free/open to everyone	Technology can be combined with other materials	National agencies should store personal data	Hacking is done by criminals	Hacking is done by everyone
Do not know	10	5	13	12	21	10	9	4
Strongly disagree	4	7	11	14	9	38	39	57
Disagree	17	22	17	25	42	56	57	91
Lightly disagree	23	31	27	25	46	39	47	58
Lightly agree	49	64	77	53	58	33	42	19
Agree	78	73	72	66	57	32	32	12
Strongly agree	65	44	29	51	13	38	20	5

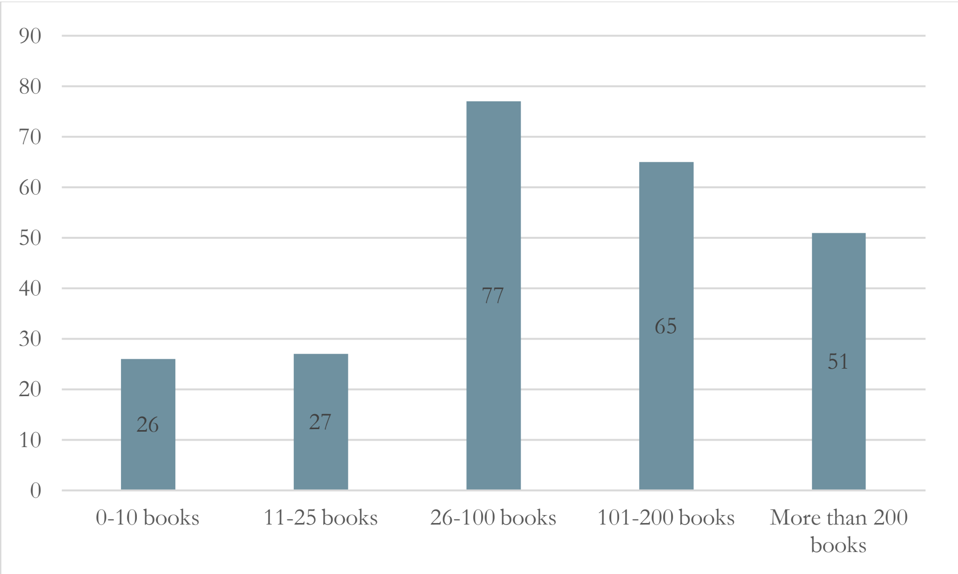
B.XI: Thoughts about the future

To what extent do you agree? I would like to/a…



	Start my own business	Future in digital design	Future in engineering/science
Strongly disagree	29	32	35
Disagree	46	66	65
Slightly disagree	40	45	58
Slightly agree	72	58	51
Agree	37	30	24
Strongly agree	22	15	13

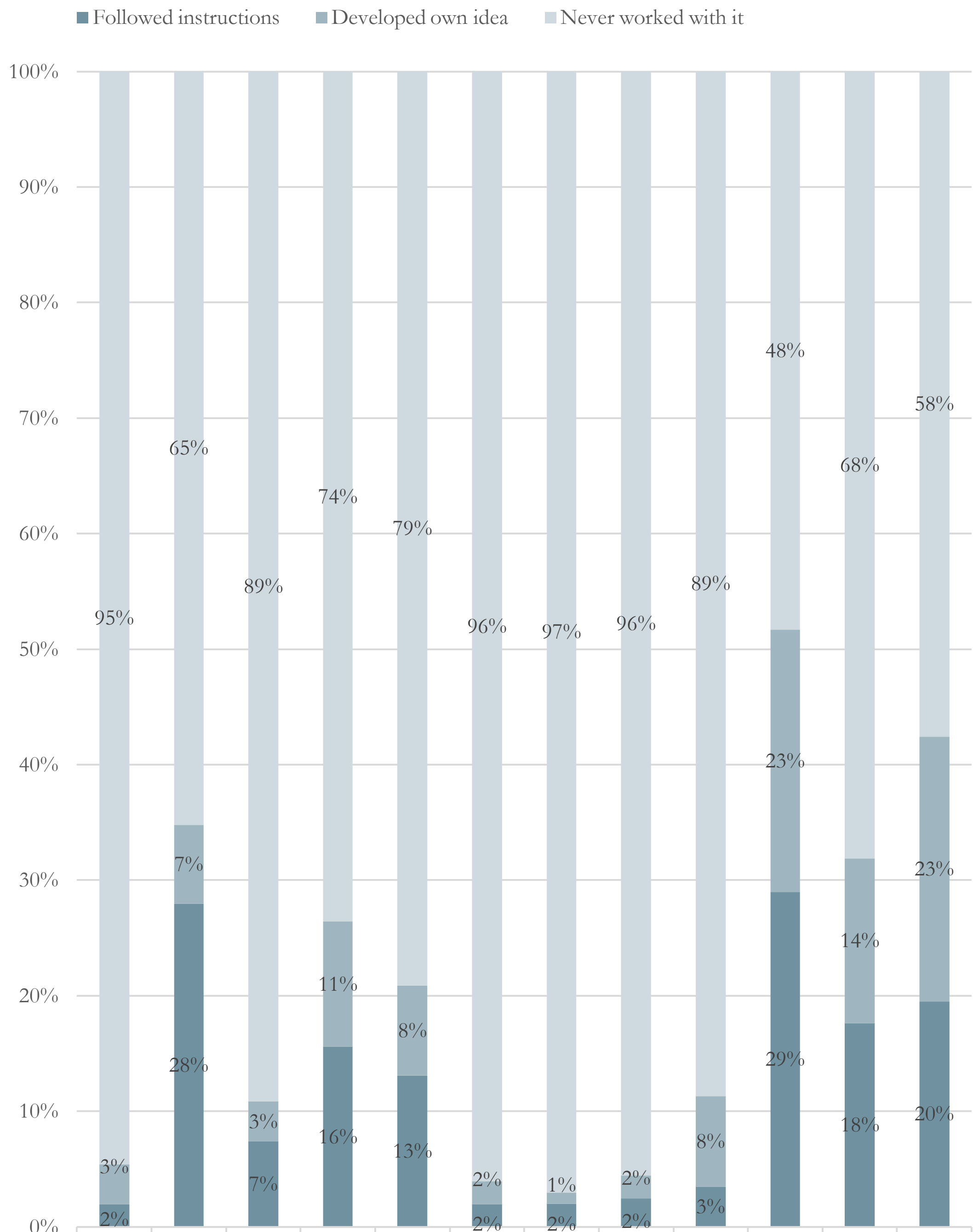
B.XII: How many books are in your home?



Appendix C: Responses from the control group

This appendix features tables charts of the FabLab group's responses on quantitative items in the questionnaire.

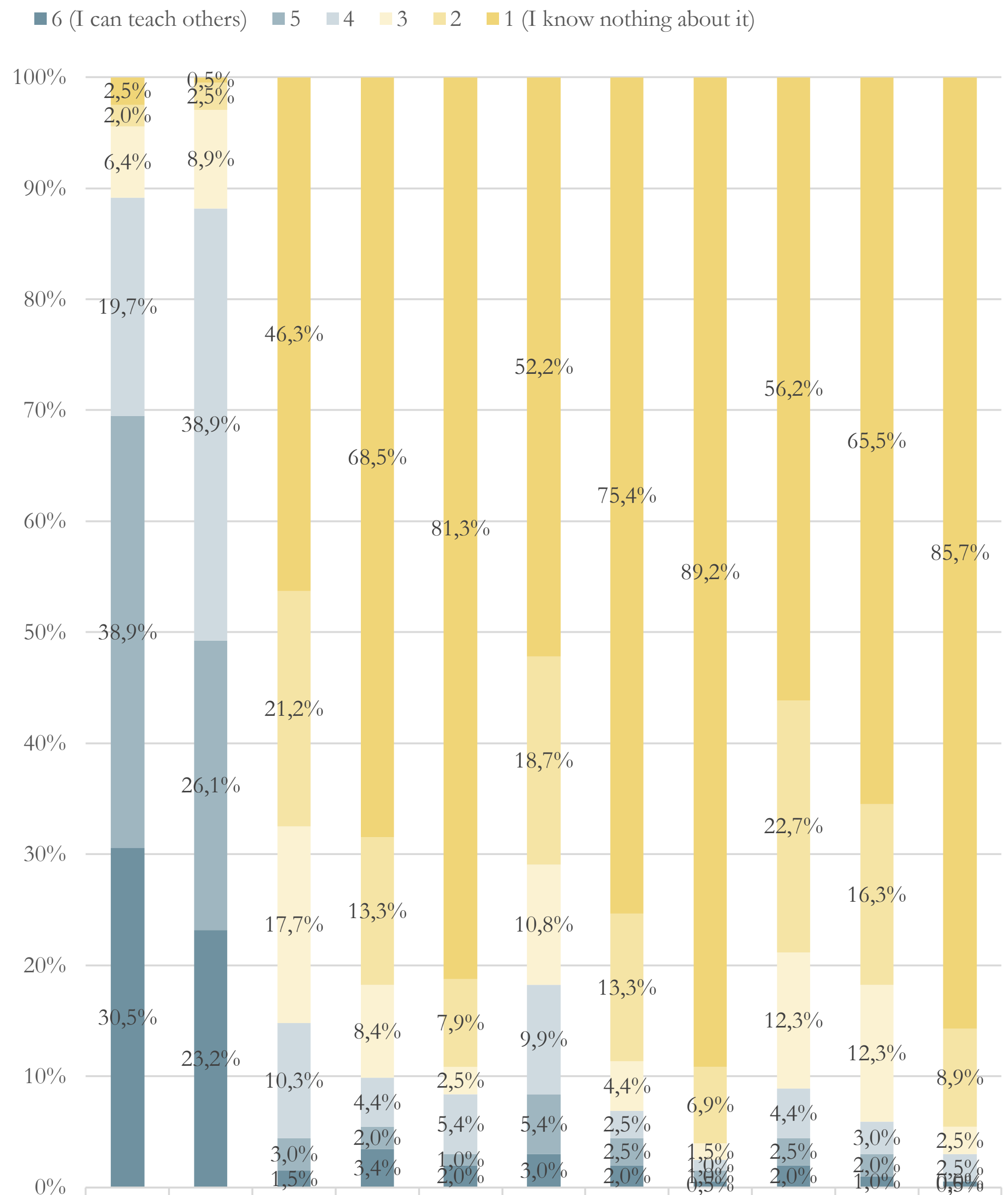
C.I: How did you work with the following technologies?



	LilyPad	Electronics	Laser cutter	Other	Textbased programming	Arduino	LittleBits	Vinyl cutter	Makey Makey	Programmable robots	Blockbased/visual programming	3D printer
Never worked with it	193	133	181	156	163	196	197	195	180	100	139	118
Developed own idea	7	14	7	23	16	4	2	4	16	47	29	47
Followed instructions	4	57	15	33	27	4	4	5	7	60	36	40

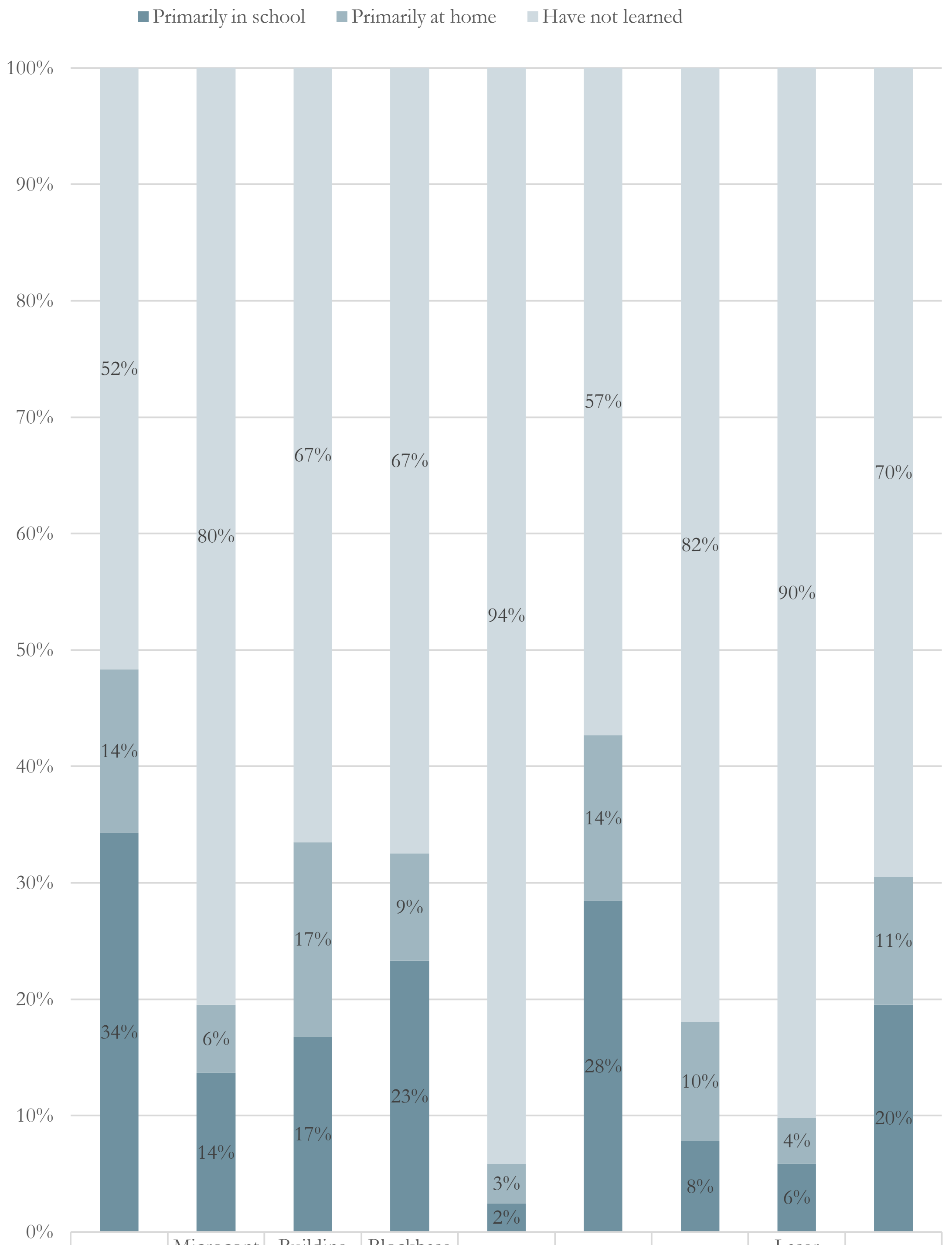
C.II: How familiar are you with these technologies?

Evaluate yourself on a scale from 1 to 6, where 1 is "I know nothing about it" and 6 is "I could teach others about it".



	Smart-phones / tablets	Com-puters/ laptops	3D printers	Block-based/ visual prog.	Micro-control-ler boards	Prog. robots	Text-based prog.	Vinyl cutter	Buil-ding elec-tronic devices	Elec-tronics/ solde-ring	Laser cutters/ CNC
1 (I know nothing about it)	5	1	94	139	165	106	153	181	114	133	174
2	4	5	43	27	16	38	27	14	46	33	18
3	13	18	36	17	5	22	9	3	25	25	5
4	40	79	21	9	11	20	5	2	9	6	5
5	79	53	6	4	2	11	5	2	5	4	0
6 (I can teach others)	62	47	3	7	4	6	4	1	4	2	1

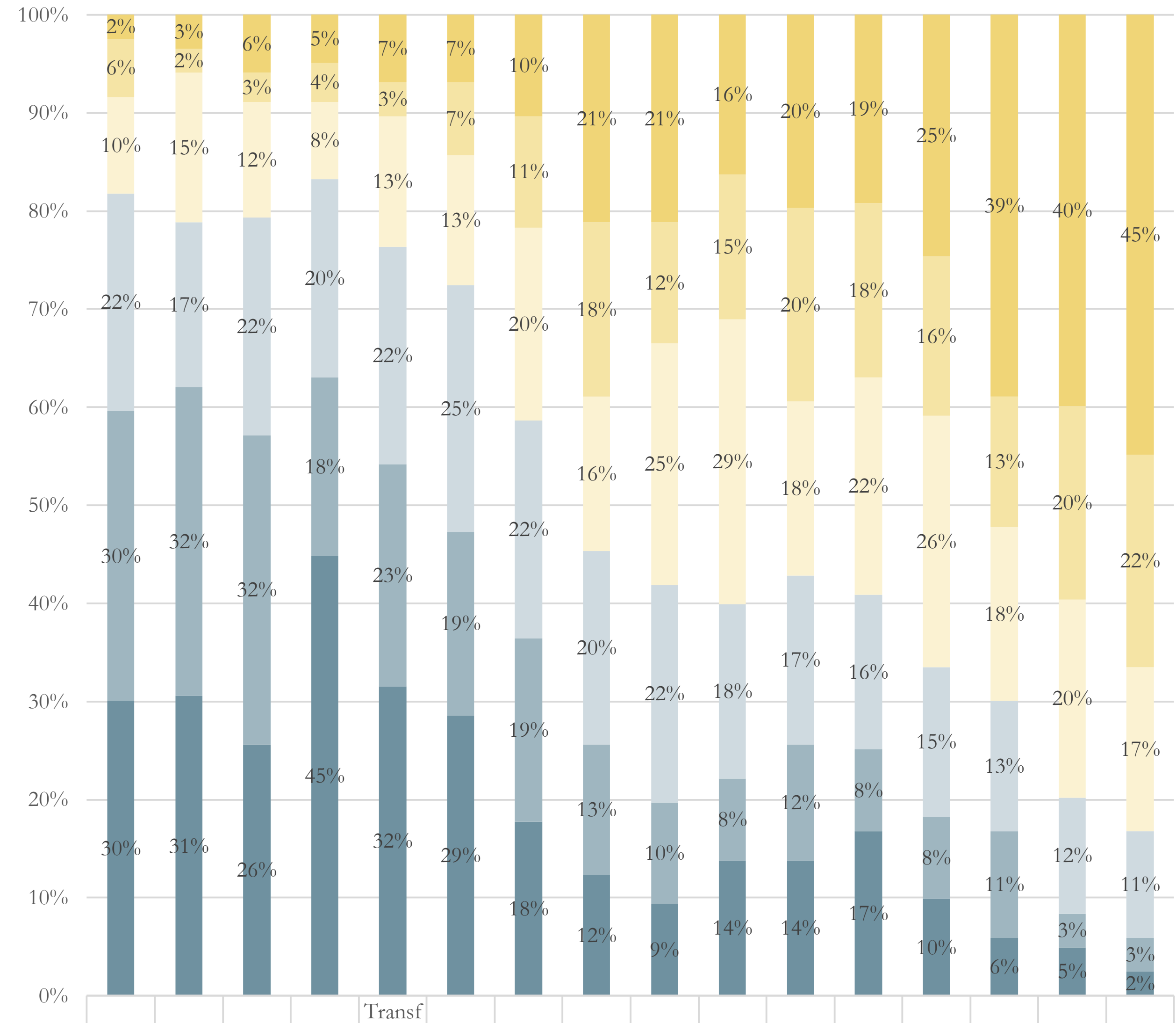
C.III: Where did you learn to use these?



	3D printer	Microcontroller boards	Building electronic devices	Blockbased/visual prog.	Vinyl cutter	Robots (prog.)	Textbased prog.	Laser cutter/CNC	Electronics
Have not learned	107	165	139	139	192	121	168	184	146
Primarily at home	29	12	35	19	7	30	21	8	23
Primarily in school	71	28	35	48	5	60	16	12	41

C.IV: Which parts of the process would be most important to you?

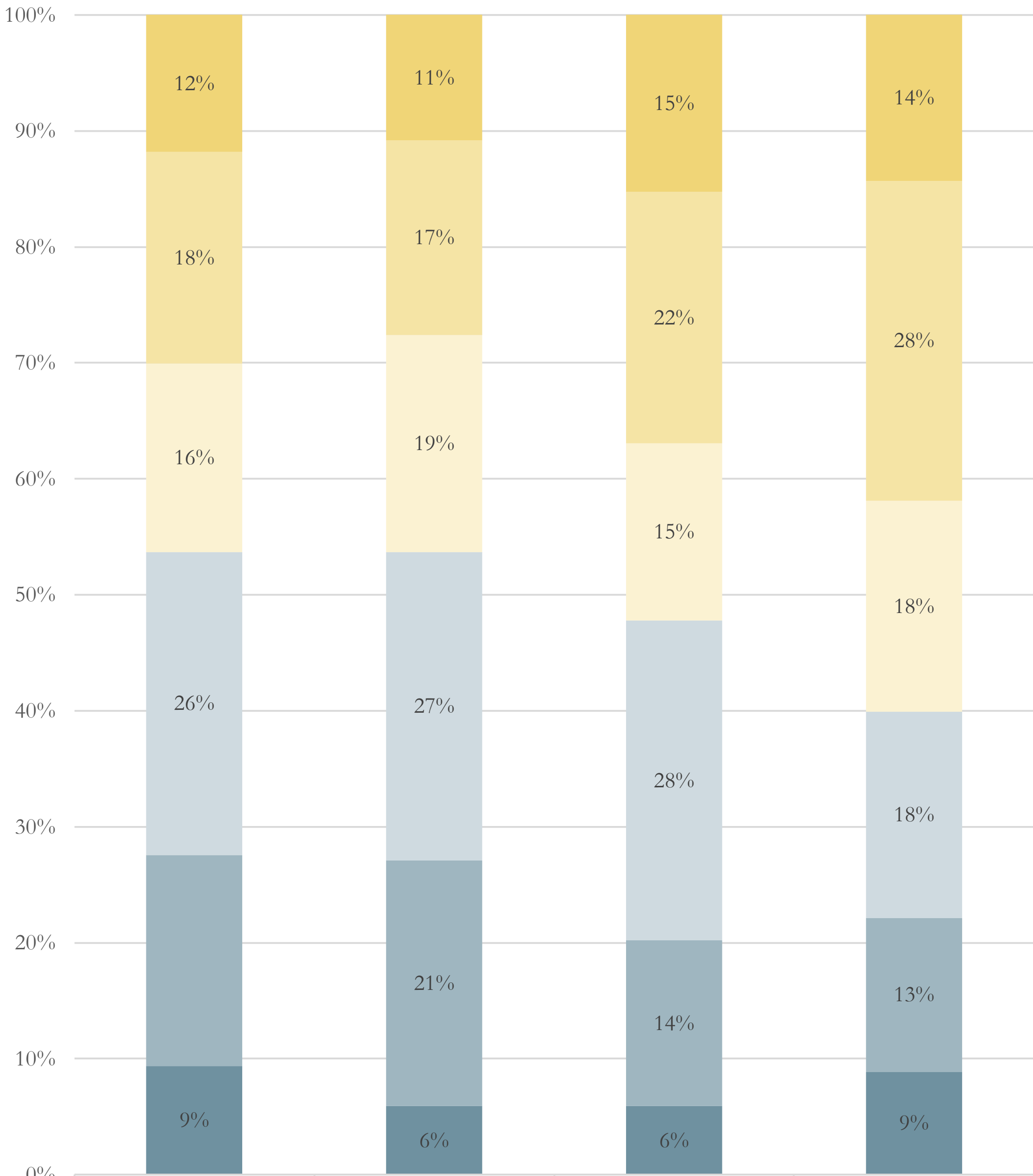
Choose a number between 1 and 6 (1 = not important at all, 6 = really important)



	All should agree	Meet w/ staff/relatives	Study nursing homes	Test solution with elderly	Transfer knowledge to future projects	Create a detailed plan	Use disagreement fruitfully	Study other countries	Sketch on paper	Patent the idea	Market solution/make money	Wait for good idea	Iterate on mock-up or sketch	Test cardboard mock-up	Stop working when finished	Build cardboard mock-up
1	5	7	12	10	14	14	21	43	43	33	40	39	50	79	81	91
2	12	5	6	8	7	15	23	36	25	30	40	36	33	27	40	44
3	20	31	24	16	27	27	40	32	50	59	36	45	52	36	41	34
4	45	34	45	41	45	51	45	40	45	36	35	32	31	27	24	22
5	60	64	64	37	46	38	38	27	21	17	24	17	17	22	7	7
6	61	62	52	91	64	58	36	25	19	28	28	34	20	12	10	5

C.V: Relationship to hacking and reparation in everyday life

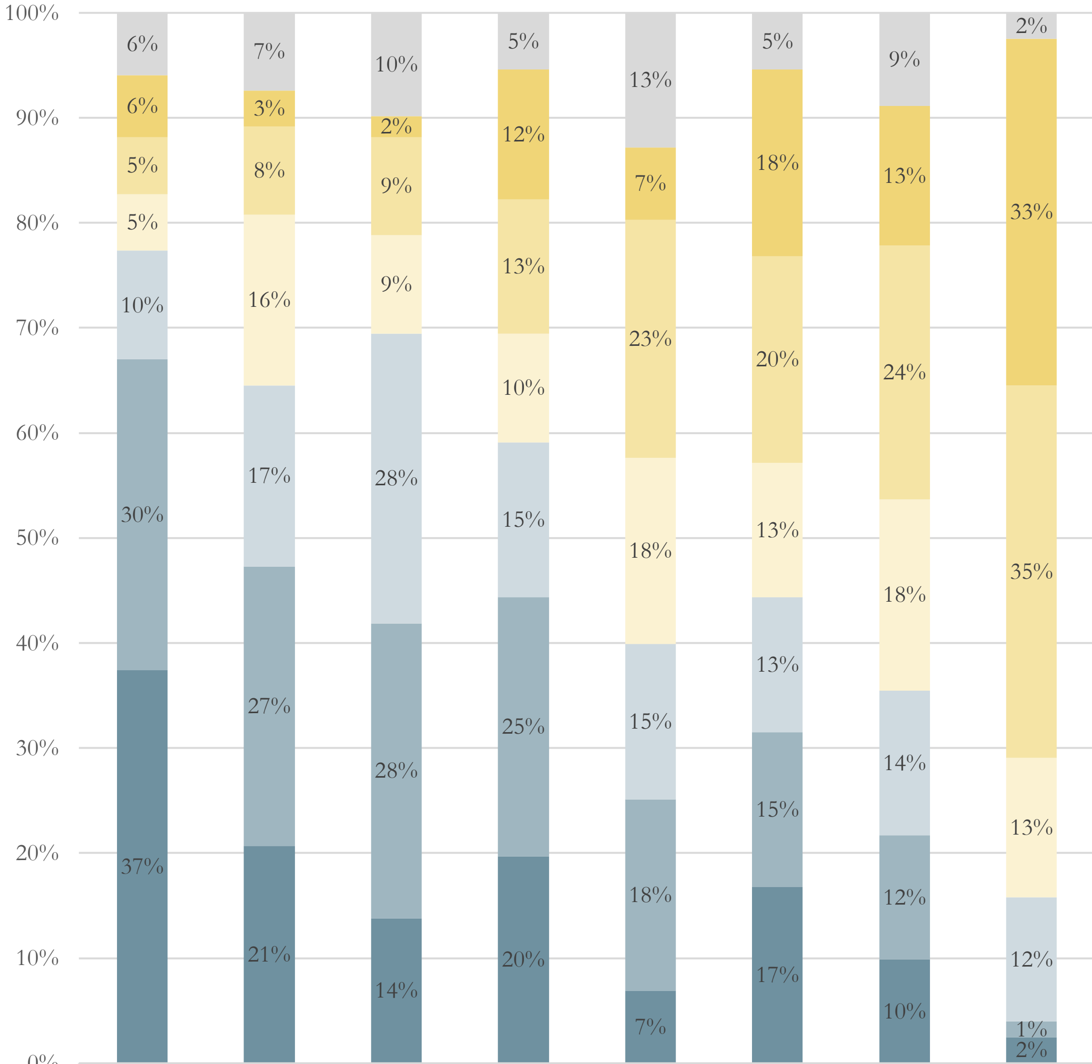
To what extent do you agree?...



	I know what is inside a phone/how it works	I want to know how they work and how to improve them	When things are broken, I think of ways to repair	Don´t care how they work, as long as they work
Strongly disagree	24	22	31	29
Disagree	37	34	44	56
Slightly disagree	33	38	31	37
Slightly agree	53	54	56	36
Agree	37	43	29	27
Strongly agree	19	12	12	18

C.VI: Technology and data

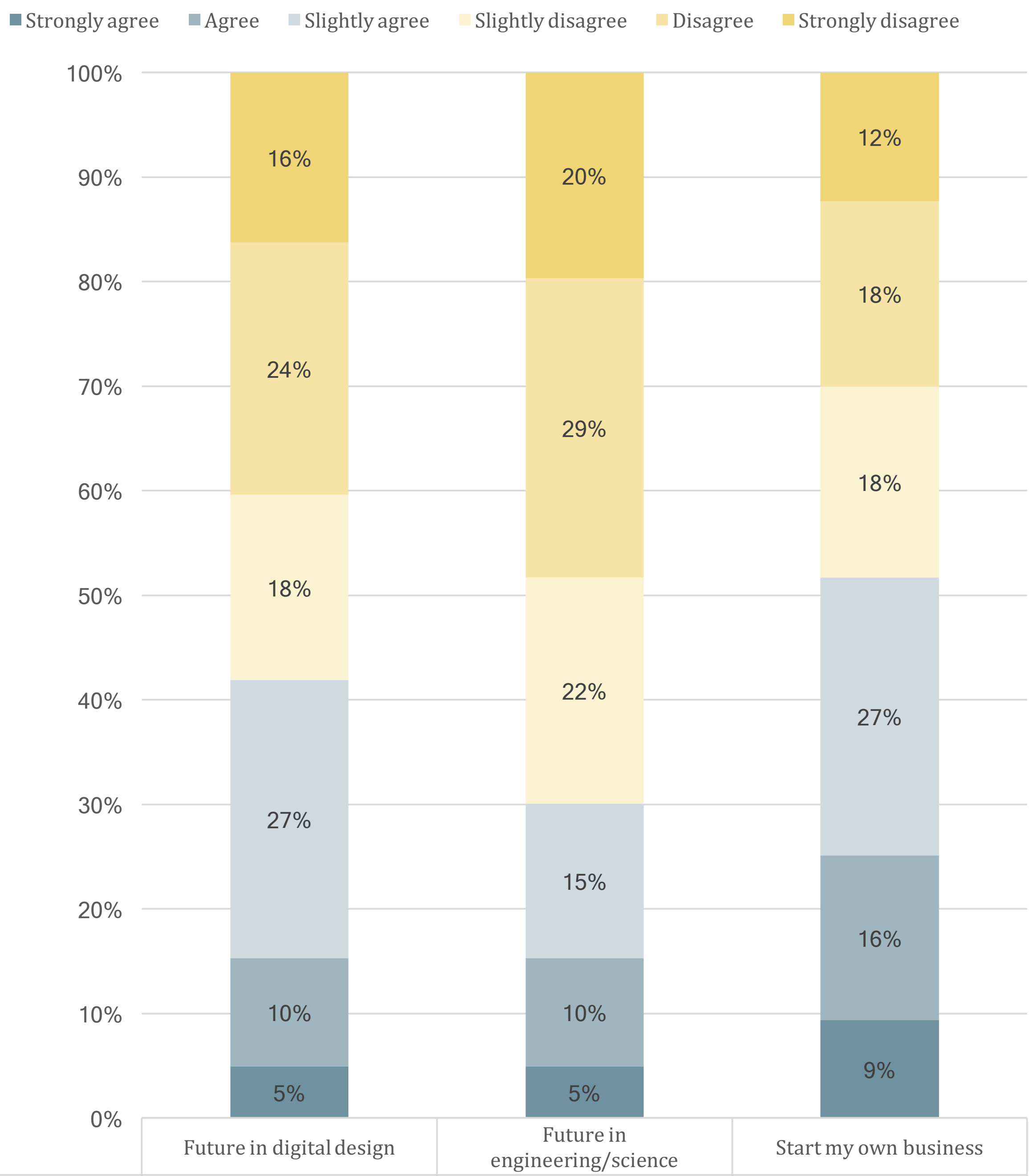
To what extent do you agree with these statements?



	Important who owns data	Technology gives me freedom to express my interests	Technology allows me to understand new contexts and opportunities	Tech./data/info. should be free/open to everyone	Technology can be combined with other materials	National agencies should store personal data	Hacking is done by criminals	Hacking is done by everyone
Do not know	12	15	20	11	26	11	18	5
Strongly disagree	12	7	4	25	14	36	27	67
Disagree	11	17	19	26	46	40	49	72
Slightly disagree	11	33	19	21	36	26	37	27
Slightly agree	21	35	56	30	30	26	28	24
Agree	60	54	57	50	37	30	24	3
Strongly agree	76	42	28	40	14	34	20	5

C.VII: Thoughts about the future

To what extent do you agree? I would like to/a…



	Future in digital design	Future in engineering/science	Start my own business
Strongly disagree	33	40	25
Disagree	49	58	36
Slightly disagree	36	44	37
Slightly agree	54	30	54
Agree	21	21	32
Strongly agree	10	10	19

Appendix D: The questionnaire

This section contains the original questionnaire in Danish. The questionnaire was administered as an online survey, and therefore the questions were displayed differently.

Digital fabrikation, design og FabLab i skolen

Velkommen til Aarhus Universitets spørgeskema om dig og dit forhold til digital fabrikationsteknologi, design og FabLab i skolen.

Personlig information

Vi vil først gerne vide noget om dig og din skole

Hvad er dit UNI-login (brugernavn)? ____________________

Hvor gammel er du? ____________________

Hvad hedder din skole? ____________________

Hvilket køn er du?

☐ Dreng
☐ Pige

Hvilket klassetrin går du på?

☐ 6.
☐ 7.
☐ 8.
☐ 9.
☐ 10.

Teknologier

Vi vil nu spørge dig om konkrete teknologier, du måske har arbejdet med i skolen. Hvordan har du arbejdet med følgende teknologier i skolen?

	Jeg har slet ikke arbejdet med denne teknologi	Jeg har fulgt en instruktion (opskrift) til at lave noget med denne teknologi	Jeg har brugt teknologien til at lave noget, jeg selv har fundet på
3D printer	☐	☐	☐
Laserskærer (Laser cutter)	☐	☐	☐
Vinylskærer (Vinyl cutter)	☐	☐	☐

MakeyMakey	☐	☐	☐
Arduino	☐	☐	☐
LittleBits	☐	☐	☐
LilyPad	☐	☐	☐
Programmérbare robotter (f.eks. LEGO Mindstorms)	☐	☐	☐
Elektronik og lodning (dioder og modstande)	☐	☐	☐
Programmering med tekst (f.eks. HTML, Processing, Arduino, Sonic Pi eller Python)	☐	☐	☐
Visuel eller blokbaseret programmering (f.eks. LEGO Mindstorms, Scratch, ArduBlock eller Weedoo)	☐	☐	☐
Andre former for digital fabrikationsteknologi?	☐	☐	☐

Skriv her, hvilke andre teknologier, I har arbejdet med. Skriv også, hvad I brugte teknologierne til.

Hvor godt kender du disse teknologier? Bedøm dig selv på en skala fra 1 til 6, hvor 1 er "*Det ved jeg ikke noget om*" og 6 er "*Jeg kunne undervise andre om det.*"

	1	2	3	4	5	6
Computer / bærbar	☐	☐	☐	☐	☐	☐
Smartphones/tablets/iPads	☐	☐	☐	☐	☐	☐
Lasercutters eller CNC fræsere	☐	☐	☐	☐	☐	☐
Vinylskærer (Vinyl cutter)	☐	☐	☐	☐	☐	☐
3D printere	☐	☐	☐	☐	☐	☐
Bygge elektroniske dimser eller simple maskiner fra bunden	☐	☐	☐	☐	☐	☐
Microcontroller boards (f.eks. MakeyMakey og Arduino)	☐	☐	☐	☐	☐	☐
Bygge programmérbare robotter (f.eks. Lego Mindstorms)	☐	☐	☐	☐	☐	☐
Elektronik og lodning (dioder og modstande)	☐	☐	☐	☐	☐	☐

	1	2	3	4	5	6
Programmering med tekst (f.eks. HTML, Processing, Arduino, Python eller SonicPi)	☐	☐	☐	☐	☐	☐
Visuél eller blokbaseret programmering (f.eks. LEGO Mindstorms, Scratch, ArduBlock eller WeeDoo)	☐	☐	☐	☐	☐	☐

Hvor har du lært det?

	Primært i skolen	Primært hjemme	Har ikke lært det
Lasercutters eller CNC fræsere	☐	☐	☐
Vinyl Skærer (Vinyl cutter)	☐	☐	☐
3D-printere	☐	☐	☐
Bygge elektroniske dimser eller simple maskiner fra bunden	☐	☐	☐
Microcontroller boards (f.eks. MakeyMakey eller Arduino)	☐	☐	☐
Bygge programmérbare robotter (f.eks. Lego Mindstorms)	☐	☐	☐
Electronik og lodning (dioder og modstande)	☐	☐	☐
Programmering med tekst (f.eks. HTML, Processing, Arduino, Python eller SonicPi)	☐	☐	☐
Visual eller blokbaseret programmering (f.eks. LEGO Mindstorms, Scratch, ArduBlock eller WeeDoo)	☐	☐	☐

Har du nogensinde arbejdet med digital fabrikationsteknologi på din skole f.eks. i et FabLab eller værksted?

Digital fabrikationsteknologi er f.eks. MakeyMakey, Arduino, vinylskærer eller 3D printer

- ☐ Ja
- ☐ Nej
- ☐ Ved ikke

Beskriv kort, hvad du har lavet, hvilken teknologi du brugte og hvad du brugte teknologien til?

1. projekt [ ]

2. projekt [ ]

I det næste, spørger vi til, hvordan det var, at arbejde med digitale fabrikationsteknologier i skolen. På nogle skoler er der et lokale, som hedder FabLab eller Makerspace, hvor man arbejde med disse teknologier.

Hvordan var det at arbejde med digital fabrikation i skolen/FabLab?

	Meget uenig	Uenig	Hverken enig/uenig	Enig	Meget enig
Teknologierne var svære	☐	☐	☐	☐	☐
Det var kedeligt at arbejde med teknologierne	☐	☐	☐	☐	☐
Jeg kan godt lide at være i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Det er interessant at lære i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Det er spild af tid at lære i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Jeg vil gerne bruge teknologierne til mine egne projekter udenfor skolen	☐	☐	☐	☐	☐
Det, vi lærer om digitale fabrikationsteknologier, kan jeg bruge i fremtiden	☐	☐	☐	☐	☐
Jeg elsker at lave projekter med digitale fabrikationsteknologier	☐	☐	☐	☐	☐
Jeg lærer meget i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Jeg tænker på det, vi har lært om digitale fabrikationsteknologier, når jeg er derhjemme	☐	☐	☐	☐	☐

I hvor høj grad er du enig i følgende udsagn? Brug skalaen fra 1 til 6, hvor 1 er "Meget uening", mens 6 er "Meget enig".

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Undervisning med digital fabrikation i skolen har lært mig at arbejde kreativt med teknologi	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har lært mig at løse svære eller komplekse udfordringer	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har hjulpet mig til at forholde mig til samfundsmæssige problemer	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har hjulpet mig til at forestille mig, hvordan jeg kan forandre ting, f.eks. med teknologi	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har hjulpet mig til at blive bedre til at samarbejde med mennesker med forskellig baggrund og evner	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har lært mig hvordan teknologi påvirker den måde, vi lever på	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har lært mig, hvordan nye ideer, ting og teknologier bliver skabt	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

I hvor høj grad synes du at forløb med digital fabrikation har hjulpet dig til ...

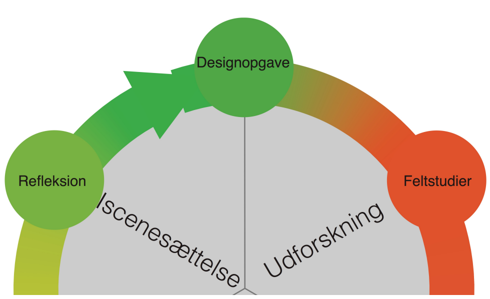
Bedøm på en skala fra 1 til 6, hvor 1 er "*Slet ikke*" og 6 er *"I høj grad*".

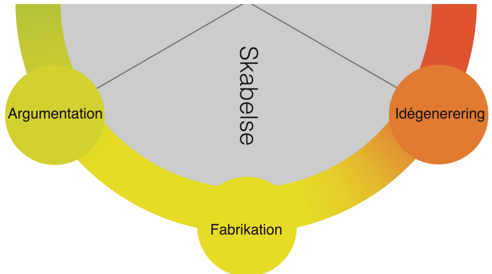
	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Undervisning med digital fabrikation i skolen har hjulpet mig til at forholde mig kritisk til min egen og andres anvendelse af teknologi (f.eks: Er vi for meget på Facebook?, er vores billeder sikre i Snapchat?, skaber vi for meget elektronisk affald?)	❑	❑	❑	❑	❑	❑
Undervisning med digital fabrikation i skolen har hjulpet mig til at kommunikere med forskellige mennesker over Internettet	❑	❑	❑	❑	❑	❑
Undervisning med digital fabrikation i skolen har lært at bruge teknologi til at arbejde systematisk med opgaver (i f.eks. fysik/kemi, natur/teknik)	❑	❑	❑	❑	❑	❑
Undervisning med digital fabrikation i skolen har øget min interesse i at ville have en videregående uddannelse	❑	❑	❑	❑	❑	❑
Undervisning med digital fabrikation i skolen har øget min interesse i at ville have en kreativ eller håndværksmæssig uddannelse	❑	❑	❑	❑	❑	❑
Undervisning med digital fabrikation i skolen har øget min interesse i at ville starte din egen virksomhed	❑	❑	❑	❑	❑	❑

Design og kreativitet

De næste spørgsmål handler om at få nye idéer, arbejde kreativt og skabe nye ting med teknologi.

Har du nogensinde arbejdet med denne model (Design Process Modellen) på din skole?





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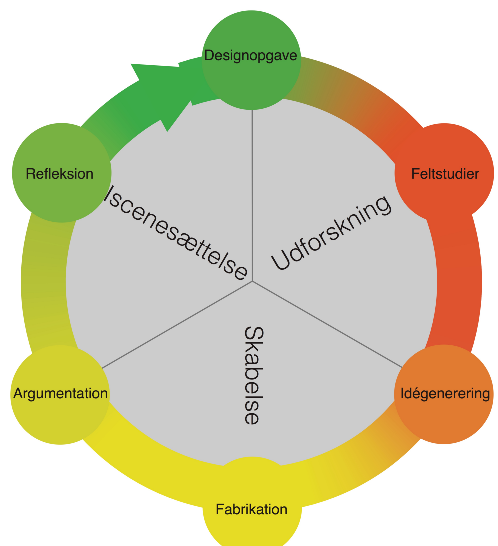
- ☐ Ja
- ☐ Nej
- ☐ Ved ikke

Hvor godt kender du enkeltdelene af Design Proces modellen? Bedøm dig selv på en skala fra 1 til 6, hvor 1 er "Det ved jeg ikke noget om" og 6 er "Jeg kunne undervise andre om det."



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	1	2	3	4	5	6
Designopgave	☐	☐	☐	☐	☐	☐
Feltstudier	☐	☐	☐	☐	☐	☐
Idégenerering	☐	☐	☐	☐	☐	☐

	1	2	3	4	5	6
Fabrikation	☐	☐	☐	☐	☐	☐
Argumentation	☐	☐	☐	☐	☐	☐
Refleksion	☐	☐	☐	☐	☐	☐

Har du nogensinde haft en idé til et nyt produkt eller opfindelse?

☐ Ja
☐ Nej

Beskriv kort din idé

Har du skabt eller bygget din idé eller opfindelse?

☐ Ja
☐ Nej

Designopgave: Plejehjemmets udfordring

I begyndelsen af 2014 forsvandt 9 bedsteforældre fra deres plejehjem pga. hukommelsestab (demens). Plejehjemmets problem er at skabe tryghed for de ældrene uden at tage deres frihed fra dem.

Hvis du blev bedt om at løse dette problem, hvad ville du så gøre?

Hvordan ville du finde den rigtige løsning på problemet med de demente ældre, som bliver væk? Hvilke dele af processen ville være vigtigst for dig?

Vælg et tal fra 1 til 6 (1 = slet ikke vigtigt, 6 = virkeligt vigtigt)

	1	2	3	4	5	6
Jeg ville lave en grundig plan for hele projektet	☐	☐	☐	☐	☐	☐
Jeg ville vente til at en god idé dukkede op	☐	☐	☐	☐	☐	☐
Jeg vil besøge et plejehjem for at udforske problemet nærmere	☐	☐	☐	☐	☐	☐
Jeg ville finde ud af, hvad de gør i andre lande	☐	☐	☐	☐	☐	☐
Jeg vil skitsere mulige løsninger på et stykke papir	☐	☐	☐	☐	☐	☐
Jeg ville bygge min idé i pap	☐	☐	☐	☐	☐	☐
Jeg vil teste min pap-model på et plejehjem	☐	☐	☐	☐	☐	☐
Jeg vil gentage mine tests med en ny skitse eller pap-model flere gange	☐	☐	☐	☐	☐	☐
Jeg vil afprøve min løsning sammen med ældre plejehjemsbeboerne	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

Vælg et tal fra 1 til 6 (1 = slet ikke vigtigt, 6 = virkeligt vigtigt)

	1	2	3	4	5	6
Jeg vil afholde et møde med plejehjemspersonale, pårørende, for at diskutere min løsning	☐	☐	☐	☐	☐	☐
Jeg vil sørge for, at alle er enige om løsningen	☐	☐	☐	☐	☐	☐
Jeg vil bruge uenigheder mellem personer/grupper til at udvikle nye idéer	☐	☐	☐	☐	☐	☐
Jeg vil tage patent på min idé	☐	☐	☐	☐	☐	☐
Jeg vil starte et firma til at markedsføre min løsning og tjene penge	☐	☐	☐	☐	☐	☐
Så snart min løsning er færdig, stopper jeg helt med at arbejde på problemet	☐	☐	☐	☐	☐	☐
Jeg vil bruge min viden fra dette projekt, i fremtidige projekter	☐	☐	☐	☐	☐	☐

Andet du ville gøre? Beskriv dem her.

Hacking, data og teknologi

Her handler det om dit forhold til hacking og reparation af teknologi i din hverdag. Hvor enig eller uenig er du...

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Jeg er ligeglad med hvordan mine digitale dimser fungerer, bare de virker	☐	☐	☐	☐	☐	☐
Jeg er interesseret i at vide, hvordan mine digitale dimser fungerer, og jeg forbedre dem ofte	☐	☐	☐	☐	☐	☐
Når jeg ser en ødelagt ting, tænker jeg straks på en måde at reparere	☐	☐	☐	☐	☐	☐
Jeg har en god idé om, hvad der er inde i en mobiltelefon, og hvordan den virker	☐	☐	☐	☐	☐	☐

Hvad gør du, hvis noget ikke virker på f.eks. din computer eller mobil? Markér tre muligheder.

☐ Ringer til en ven

☐ Læser i en manual

☐ Spørger en af mine forældre

☐ Ringer til support

☐ Søger på problemet på Internettet

☐ Søger efter hjælp på specifikke hjemmesider

☐ Starter en diskussion på en f.eks. et forum

☐ Roder med forskellige indstillinger, kommandoer osv., som jeg kender

☐ Ved det ikke

☐ Andet. Skriv venligst her:__________

Har du nogensinde skilt din telefon eller andre digitale dimser ad?

☐ Ja

☐ Nej

☐ Ved ikke

Hvorfor åbnede du den? Var det f.eks. for at fikse/forbedre noget?

Hvorfor ikke?

- ☐ Hvorfor skulle jeg?
- ☐ Det kan jeg ikke finde ud af
- ☐ Så ville jeg bryde garantien
- ☐ Ved ikke
- ☐ Andet. Skriv det venligst her:__________

Hvor enig er du i disse udsagn om teknologi og data?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig	Ved ikke
Teknologi, data og information bør være åbne og tilgængelige for alle	☐	☐	☐	☐	☐	☐	☐
Staten skal gemme alles personlige data og information	☐	☐	☐	☐	☐	☐	☐
Jeg går op i hvem der ejer mine data og informationer, f.eks. billeder og musik	☐	☐	☐	☐	☐	☐	☐
Hacking er kun noget kriminelle gør på internettet	☐	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

Hvor enig er du i disse udsagn om teknologi og data?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig	Ved ikke
Hacking er noget alle gør	☐	☐	☐	☐	☐	☐	☐
Teknologi giver mig frihed til at udfolde mine interesser	☐	☐	☐	☐	☐	☐	☐
Jeg kan se hvordan teknologi kan kombineres med andre materialer (f.eks. stof, træ eller papir)	☐	☐	☐	☐	☐	☐	☐
Teknologi giver mig mulighed for at forstå nye sammenhænge og muligheder	☐	☐	☐	☐	☐	☐	☐

Din fremtid

Til sidst vil vi gerne vide, om du eventuelt kunne finde på at overveje en fremtid indenfor teknologi, design naturvidenskab eller som selvstændig. Vi spørger også til, hvor mange bøger, I har, der hvor du bor.

Her spørger vi dig om dine tanker for fremtiden
Hvor enig er du?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Jeg vil have en fremtid indenfor teknologi og design	☐	☐	☐	☐	☐	☐
Jeg vil have en fremtid som ingeniør eller indenfor naturvidenskab	☐	☐	☐	☐	☐	☐
Jeg vil starte min egen virksomhed	☐	☐	☐	☐	☐	☐

Hvor mange bøger er der ca. i dit hjem?

(du skal ikke tælle blade, aviser eller dine skolebøger med)

- ☐ 0-10 bøger
- ☐ 11-25 bøger
- ☐ 26-100 bøger
- ☐ 101-200 bøger
- ☐ Over 200 bøger

Tusind tak for din hjælp med at besvare vores spørgeskema.

Hvis du har andet at fortælle om dit forhold til teknologi, eller ideer til hvordan fremtidens skole kan bruge teknologi i undervisningen, så skriv dem gerne her:

Mange hilsner
Ole, Rachel, Kasper og Mikkel
Aarhus Universitet