BARRIERS AND OPPORTUNITIES FOR 3D PRINTING IN DANISH SCHOOLS: A QUALITATIVE STUDY

Anders Bod Lund¹, Helga Negendahl¹, Dorte Hammershøi², Thomas Ryberg³

¹ Aalborg University – Engineering Psychology Master’s Programme (DENMARK)
² Aalborg University – Department of Electronic Systems (DENMARK)
³ Aalborg University (Denmark) – Department of Communication and Psychology (DENMARK)

Abstract

The advent of affordable 3D printing has provided the possibility for its use in educational settings. Previous studies have demonstrated the benefits and possibilities of these technologies in education [1] [2] [3], and to understand which factors that affect the use of 3D printers in education, an exploratory pilot study was performed, and followed up with a more confirmatory field study. 3D printers were introduced in four different schools in Denmark, and the opportunities and barriers related to the technology were investigated in the pilot study. The participating teachers had responsibility for integrating the technology into their classrooms, and could use them as they found best. Data from the pilot study was gathered from three sources: Semi structured interviews with the participating teachers; open ended questionnaires collected from 67 participating pupils; and field observations of the participating classes. All sources of data were analysed using Robert Yin's five-fold method [4]. Although the teachers did have successful instances of teaching with the 3D printers, the researchers found that improvements could be made. Some practical issues were found, such as little printing capacity which resulted in decreased motivation, due to the long waiting time between finishing a design and printing it out. The teachers struggled to plan learning activities that could provide rich and challenging design processes. To better structure a learning activity, a new approach was introduced and tested in the field study, where the printing capacity was also increased. This approach included having the pupils design objects that could be assessed quantitively on two parameters, either by calculations or experimentation, and afterwards plotting the results on a coordinate system. By testing this approach in an authentic teaching situation indications were found that this approach would support the desired rich and challenging design process, but that it could also support learning of many 21st century skills among other learning opportunities.

Keywords: Digital Fabrication, Maker Education, Teaching Aids, 3D printing, 21st century skills, Tinkering.

1 INTRODUCTION

Maker culture in the form of Fablabs, maker fairs, and maker spaces delivers promises of integrating the ideas of progressive education and inquiry based learning with powerful and revolutionary technologies [5]. This unique combination provides children with the possibility to explore STEM fields in a personal and meaningful way [1] [5] [6]. STEM competencies are desirable for a wide range of industries, similarly maker education can also provide an opportunity to develop 21st century skills. The formulation of these skills is an attempt to define which skills will be necessary in a world where many "traditional" jobs are disappearing, in what is sometimes referred to as the fourth industrial revolution. Maker education places a strong emphasis on many of these skills, through its roots in the pedagogical traditions that also highlight these skills. Further, it adds the technological dimension [5] [6].

However, a question remains on how to actually implement the necessary changes, that will facilitate the teaching of meaningful STEM subjects and 21st century skills, or how to get teachers, who were taught 20th century skills, to teach those of the 21st century. The role of the educator in maker education is different from that of traditional classroom teaching, and how maker education relates to existing curricula [5] remains to be addressed. One of the most profound differences is how mistakes or errors are perceived. In traditional recall based education, error is seen as an indication that the pupil is not learning; however, in maker education, mistakes are seen as essential leverage for learning, as the very situation where a child has the possibility to improve and iterate upon a product and facilitate a process otherwise impossible to achieve. This shift places the teacher in the role of
coach, or co-creator, rather than a provider of existing knowledge that should be remembered by the child as accurately as possible. According to Vossoughi [5] maker education often makes use of hybrid pedagogies in which pupils, in some stages, are working independently and exploratory, and, in other stages, demonstrations, facilitated workshops, and critique are used. Literature also describes several pitfalls and threats to successful maker education; one example being the “key chain syndrome” described by Blikstein [1], or the danger of focusing too much on the tools involved or focusing narrowly on STEM fields [5] [6]. The keychain syndrome refers to a tendency that children will find a somewhat trivial object so fun and exciting to construct, that they will not pursue more complex and challenging tasks. This effect is often observed when creating keychains, since this object can provide too big reward for too little effort, since the object is simple to create, but offers a professional looking personal object. This illustrates that some educators and researchers at times struggle to push maker education beyond certain narrow focusses and deliver the promises of maker education fully.

Different approaches have been proposed on how to create successful instances of learning within maker education. Two books in the Invent to Learn series by Sylvia Martinez and Gary Stager [6], and David Thornburg, Norma Thornburg and Sara Armstrong [7], provide an attempt at a comprehensive guide for implementing maker technologies successfully in schools, including information about the different technologies and guides to creating meaningful projects. Vossoughi et al [8] builds the case that even though maker education promotes equity and democratization of technologies, the movement has yet to demonstrate its true potential for equity among genders and ethnicities. One of the ways they propose to achieve these goals is by using certain types of language and social interactions, which their study indicates, can empower children and provide them with self-confidence and pride in their work [8]. Smith et al [2] adds that introducing the concept of design thinking can provide children with “a general understanding of the creative and complex process through which artifacts and futures emerge in processes of digital fabrication.”. Thus, different approaches are currently available for educators who wish to embark on the journey towards introducing maker education in their schools. However, the range of different approaches are still somewhat sparse compared to other pedagogical traditions due to the novelty of the field. The purpose of the present contribution is to propose more tools and expand the range of possibilities for educators wishing to engage in maker education.

2 PILOT STUDY

The study was initiated in the fall of 2016 with a collaboration between the Danish company Create it REAL and the Municipality of Aalborg, a municipality with a population of 210.316 located in Northern Denmark. Create it REAL is a research and development company for 3D printing that specializes in enhancing speed and precision of 3D printers through the use of an advanced control system. This means that the maker technologies included in this study are limited to 3D printers, and, more specifically, to a model named Ideawerk Speed, a 3D printer Create it REAL developed for the Chinese education market with the company Weistek. Together, Create it REAL and the Municipality of Aalborg launched a pilot project to investigate how 3D printers could be introduced in education, and what value it could add to local education institutions. Therefore, an opportunity was given to six schools in which the Municipality of Aalborg and Create it REAL provided financial and technical support. The teachers included in the project taught 6th, 7th and 8th grade, so the study is based on teaching activities for an age group of approximately 12-14 year old pupils. In turn, the schools provided feedback and shared their experiences about teaching with the 3D printers. This also provided an opportunity to investigate how 3D printers are introduced to teachers and how teachers introduce the technology to pupils. In this study, observations will be extracted from these experiences, and these will be used to develop a new approach of introducing 3D printers to pupils with the purpose of unleashing the potential of maker education in order to teach 21st century skills.

2.1 Methods

The recruitment procedure consisted of an employee from the Municipality of Aalborg writing an email to all non-private schools under his jurisdiction, offering them the possibility to participate in the project. The schools had to pay a small entrance fee, and the Municipality of Aalborg would then finance the 3D printers and filament. Six schools started out in the project, but two dropped out. Of the four remaining schools, two were considered rural, one suburban, and one urban. Three of the schools received one 3D printer, and one of the schools received two; all of the model Weistek Ideawerk Speed. The schools did not receive any other maker technologies as part of the project, however, some already had experience with LEGO Mindstorms, and the programming language
Scratch. The researchers also provided technical support during the project, as well as a limited amount of suggestions on how to use the technology for teaching.

During this time, the exploratory part of the research project began. The underlying research question was: What are the potentials and barriers for introducing 3D printing in Danish schools? In this study, a generally qualitative approach was taken, since the subject matter at hand would take place in highly complex and “messy” situations. Furthermore, due to the sampling process, it was not feasible to obtain a valid control group for comparison. Thus, the subject matter was investigated by gathering data from three different sources; semi structured interviews with the four teachers involved; open ended questionnaires handed out to 68 pupils; and 11 pages of field notes from teaching situations. All field studies were conducted by Helga Negendahl and Anders Bod Lund (“the researchers” in the following). One teacher from each school was interviewed; these were the teachers who had almost exclusively used the 3D printers in the project. The interviews were conducted from mid-December to mid-February, meaning that the teachers who were interviewed later were somewhat further ahead in the process than the first. The questionnaires for the pupils were handed out and answered during the 31st of January, as all the pupils involved in the project met and would go through several workshops that day, including the questionnaire. Finally, field observations were primarily conducted during a theme week at a school in which the pupils had to design mobile accessories for 3D printing during an entire week.

The three sources of data were analyzed separately using Yin’s fivefold method [4] adapted to each type of data. After analyzing and interpreting the data separately, a discussion and interpretation of the emerging themes across all sources of data was performed. Three overall themes were found: motivation, resources, and teaching opportunities. These themes will be explained in the next three sections.

2.2 Motivation

In general, it was found, in all three sources of data, that the pupils had varying degrees of motivation. This led some teachers to suggest in the interviews that 3D printing should be an elective class, leaving only the most motivated and skilled pupils. It was found that two factors primarily had an effect on motivation: 1) The pupils would experience a long waiting time between finishing the design and having the actual printed object, and this would decrease their motivation. 2) It was seen during the observational study and reported in the interviews that creating a personal object would usually improve the pupils’ motivation, but that it would also sometimes decrease the learning potential. This is in contrast to much of the existing literature in maker education where the opposite is claimed; that by creating something with personal meaning STEM fields and other topics are learned more easily [1] [2] [3] [5] [6]. However, this might be an example of the “keychain syndrome” described by Blikstein [1], and that the perceived lack of learning stems from the teacher’s inabilities to move beyond simple projects with a high reward to intellectually challenging problem solving.

2.3 Resources

There was occasionally a long waiting time between finishing a design until the pupils would have the printed products for evaluation. This can be seen, for instance, through replies to the questionnaire in which some pupils explained that they had learned patience through working with the 3D printers. This was mainly because there were between 12 and 25 pupils to a single 3D printer in most cases, and this was far from enough to keep up with the number of designed objects. This lack of capacity meant that most of the teachers would take over the control of the printing process, gathering all the design files at the end of a designing session, and printing them during the week. This meant that the pupils would not receive the printed product until the next 3D printing lesson, and, in general, the pupils would not control the printing process of their design. This method of printing removes the possibility for going through a truly iterative process. Deci and Ryan [9] also describe lack of control as a major factor contributing to lack of motivation, which, in turn, decreases the possibility and effectiveness of learning.

2.4 Teaching opportunities

The teachers in the project also mentioned plenty of opportunities for interesting learning situations. These include the potential for interdisciplinary curricula, including projects that connect 3D printing to other topics or technologies. Our observations also showed some instances of pupils going through an iterative design process to reach a self-determined goal, but it was also seen that many pupils were
victims of the keychain syndrome and would simply find a predesigned mobile cover, write their name on it, print it, and be content with the result. Thus, the opportunities for rich intellectual design processes and exploration of STEM fields were obviously present, but they were not necessarily realized. In this regard, it should also be mentioned that all the teachers in the present study were novices when it came to 3D printing. In addition, very little predefined material was at their disposal, and even less in Danish. This meant that many teachers prepared their own material for teaching activities using the 3D printer. The teachers mentioned that, with little time to prepare before each class, this could be a challenge, especially when a lot of the time was used to fix printer jams as well as printing the objects from previous classes. Therefore, we sought to find an approach to use the 3D printer that would support exploration of STEM fields, and minimize the keychain syndrome, especially for teachers new to maker education.

3 THE ORESMIAN COORDINATE SYSTEM

Based on the results of the exploratory study, a creative idea generation session was performed by the researchers based on the principles described by Hansen and Byrge [10]. This method includes providing carefully selected stimuli during the idea generation phase in order to escape obvious ideas, and create novel and innovative ideas by forcing the participants to apply their previous knowledge in new contexts. This method proved to be very productive and resulted approximately 50 ideas. Of these, only a few were selected to be further refined and implemented. In the end, only one was implemented in an authentic situation. This was, what we dubbed, the Oresmian Coordinate System (OCS), a rectangular coordinate system named after the French natural philosopher and astronomer Nicole Oresme who utilized a rectangular coordinate system and pre-dates René Descartes, whom the rectangular coordinate system is elsewise named after. This coordinate system would in our proposal be a physical entity made from large pieces of paper.

The idea of the OCS was conceived on the background of the teachers’ apparent lack of strong structured ways of utilizing the 3D printers for STEM projects, and it was created to accommodate that need, while still supporting the open-ended questions that maker education endorses. Another source of inspiration for the OCS was a learning activity that was encountered previously to this study; here the pupils would design and 3D print models of highway bridges, stress test them by adding weights until they would break, and calculate the price of materials for building the bridges in real life. Although no data was gathered from the learning activity it is considered successful, achieving the type of intellectually challenging problem solving and an iterative design process that can fulfil the promise of maker education. Furthermore, it seemed that the act of breaking the designed object, seemed to be an effective means of avoiding the keychain syndrome, since created a higher emphasis on reflection and process awareness. The OCS is a somewhat simple, although powerful addition to this, and simply adds a coordinate system with the strength of the bridge along one axis and the cost of the bridge along the other. When a bridge would have been designed, printed, and tested, it would be placed on the OCS, at the coordinate that corresponds to its price and strength. The hope was that the OCS would thereby create a sense of direction in the design process, since the best bridge would be placed as low on the x-axis and as high on the y-axis as possible, creating the perfect compromise of price and strength. It was hoped that the coordinate system would achieve things such as: 1) Providing the pupils with a tinkering mind-set by promoting continuous problem solving, 2) providing the pupils with a visually accessible tool for planning their next iteration, based on lessons learned from the current and previous iteration, 3) providing the teacher with a tool to monitor the pupils’ design process, and 4) serve as a method of presenting an overview of the design process to peers. These are closely related to 21st century skills, which other researchers have also highlighted as interesting learning possibilities within maker education. These include, problem solving, knowledge construction, collaboration, which are all skills we hope the coordinate system will train. A more precise definition of these skills can be found below. Even though the OCS was envisioned with the bridge design in mind, it was hoped that it would be a flexible tool that could be used in a broad variety of learning activities.

4 FIELD STUDY – TESTING THE ORESMIAN COORDINATE SYSTEM

After conceiving the idea of the OCS, it was decided to test it in an authentic classroom setting, to test if this approach would make it possible to achieve more iterations and problem solving, while avoiding the keychain syndrome. It was therefore decided to conduct a field study in which the system could be tested in one of the schools participating in the project. The school had planned a theme week where
one of topics was "technology and gaming development" which around 36 pupils had chosen to participate in during the week. The school was interested in trying out a new learning activity and the researchers then helped to plan this activity. The teacher who had the responsibility for this activity was new to 3D printing. She will be referred to as Rachel in the following.

4.1 Method

During this week, two of the researchers, Anders Bod Lund and Helga Negendahl, would participate to gather data, but also to act as helpers and technical support. This meant that the role of the researchers was as action researchers. However, Rachel had the main responsibility for the learning activity during the week, and the researchers adopted to a higher degree the role of observers compared to the pilot study. The main source of data during the week was field notes and video recordings. The video recordings were unfortunately limited by the fact that not all the parents of the pupils had signed consent forms allowing for video recording. Thus, only the pupils who had signed consent forms were recorded. The video data and field notes were coded mostly for instances of 21st century skills and analyzed with the fivefold method [4]. No official list of official 21st century skills exists; however, a Danish government agency has provided a list of six 21st century skills, based on the ones defined by Microsoft, and these are as follows: Collaboration, real world problem solving and innovation, knowledge construction, competent communication, skilled use of information and communication technology, and self-regulation [11]. To deepen our understanding of the data, a video review session was also planned in which Rachel participated, as well as another teacher who had been responsible with teaching using the 3D printer prior to the theme week, here referred to as Bruce. This provided the opportunity to relate some of the video recordings to the teachers’ previous experiences with 3D printing activities.

4.1.1 Preparing for the theme week

From the preceding pilot study, the researchers had several ideas of what would support a successful learning activity during the week. Therefore, several actions were taken. First, the printing capacity was increased significantly, and the aim was that groups of about three pupils should share one 3D printer. Therefore, extra 3D printers were provided by Create it REAL for the week. This was to make it possible for each group to plan their own time and printing process, providing a deeper understanding of the actual manufacturing process. In the exploratory study, the teachers had requested activity plans, and the researchers therefore provided a guide that would help the teacher facilitate the workshop with designing, testing, and evaluating their designs using the OCS. The guide also included 1) a general introduction to 3D printing and its impact on society, 2) guides for the use of CAD software, 3) a description of an iterative design process, 4) a guide to Create it REAL’s printers, and 5) a problem statement for the workshop.

4.1.2 Structure of the week

During the theme week, the 7th, 8th and 9th graders who chose the “technology and game making” activity would participate in this workshop. During the first three days (Monday, Tuesday, and Wednesday), the pupils would rotate between three different workshops, trying a new one each day. The other workshops were eSports and LEGO Mindstorms. This meant that the researchers had a unique possibility to test out a predefined learning activity using the OCS each of these days, and adjust the learning activity as needed. During the last two days of the week (Thursday and Friday), the pupils could choose between the three different activities that they had tried during the week. During these two days, only eight pupils chose 3D printing. These eight pupils worked on three different projects, each with very different foci and with different design processes and motivations. Therefore, the data extrapolated from the final two days will be treated more as a type of case study, due to the small group of pupils and the intensity of the data from these.

4.1.3 Sampling

From the researchers’ point of view, the sampling can be seen as an opportunity sampling, since the school provided and planned the theme week initially without help from the researchers, but later invited the researchers to help plan the activity. Therefore, the researchers seized the opportunity and got a group of pupils to test out the idea, in order to extract data. During the first three days, between 11 and 13 pupils worked with 3D printing each day, and, in total, 37 pupils worked with 3D printing. This was considered a somewhat large sample, due to the general circumstances, and, therefore, general aspects of the activities in these days can be found through qualitative analysis. The sample
has some inherent biasing issues, as the pupils could choose themselves what they wanted to do during the theme week, with only one of the themes being technology focused. Therefore, the sample of pupils are believed to be somewhat biased, as the pupils will most likely be the ones most interested in technology in the first place. Perhaps, because of this, a gender bias can also be seen, as only four girls and 33 boys participated.

4.2 Findings

In the following, the findings from the field study and the video review session of it will be presented. The data from both these sessions were analyzed by coding it, with a special emphasis on the 21st century skills that were identifiable during the coding. The analysis was focused on the instances, where the OCS or testing were present, since this study was focused mainly on investigating the effects of these. The findings will be parted into three segments: bridges, boats, and spinning tops. These reflect three different projects that the pupils engaged in during the week. All the 37 pupils engaged in the bridge project during the first three days. The spinning tops was a project envisioned by a pupil, hereafter referred to as Fred. Fred worked alone on the project during Thursday, but Friday he was joined by another pupil, hereafter referred to as Mick. Fred found a design for a gear driven spinning top online and decided to try to improve this design. The parts were printed, and the spinning top was plotted on the OCS with weight and average spinning time. Fred and Mick worked together and, in the end, they created a tournament in which the different versions battled each other. In addition to the spinning tops, another group created boats. In this group, two pupils participated Thursday, and four participated Friday, however, only one pupil participated both days, meaning that five pupils participated in total. The boat group designed and printed boats. The boats were also plotted on the OCS, with the weight of the boat and the weight of the maximum load as the axes. The boats were tested in a small bowl where they were placed in water, and afterwards weights were placed in them. Finally, another group chose to make fidget toys, however, they were not included in the analysis for various reasons. First, they did not have signed consent forms, and, therefore, no video data was obtained. Second, they did not apply the OCS in their process.

4.2.1 Bridges

The bridges were tested by placing weight on top of them in the form of paper stacks. Afterwards, they would be plotted on the OCS, and then Rachel would have prolonged conversations with the pupils regarding their design, ideas, issues, and plans. Rachel would guide the pupils, but not directly take charge of the process. The testing of the bridges was seen as a quite motivating factor, and this was verified by the teachers during the review session.

![Figure 1. A picture of two testing scenarios. On the left a testing of a bridge is performed, with multiple pupils working together. On the right a boat can be seen with an uneven weight distribution.](image-url)
to a much higher degree of collaboration between the groups. The stack of paper that was placed on top of the bridge would be in the range of 1.5 meters, and, as such, the stack had to be supported by the pupils. Finally, the weight of the paper was, more often than not, not enough to actually break the bridges, and, by their own initiative, the pupils would sit on top of the paper stack. To ensure a somewhat continuous way of adding weight, the lightest pupils would sit on the stack first, and as the test went on the heavier pupils would sit on top of it. Because of this, the testing became an activity requiring the participation of most of the class, and almost everyone followed the process carefully. Finally, the OCS was placed on the teacher’s desk. After the testing was performed, and the price of materials was calculated, the teacher asked pupils to come up to the coordinate system to place the bridge along with a post-it note stating the strength and price of the bridge. Here, some interaction between the groups happened, although not to the same extent as in the testing situation. After the placement of the bridge and the post-it was completed, the groups would return to their own desks and design a new version. The fact that different areas of the classroom were tied carefully to the different phases of the development also meant that it was easy for the teachers and researchers to identify which phase the pupils would be in at different times.

4.2.2 Boats

The group who made boats investigated how much weight a boat could load before sinking. In the coordinate system, they plotted the weight of the boat along one axis, and the weight of the load along the other, trying to create a light design that could hold a heavy load. Here, the testing situation was seen as being somewhat less fun and exciting compared to the other testing situations, but the teachers in the review session believed that it was also rich in learning possibilities. This was also one of the videos that was viewed, where Rachel spoke a lot with the pupils, but mostly in a guiding and inquiring way. Rachel verified this in the review session, and explained that it was her intention. When asked what role they thought she had in the clip, the teachers replied as follows:

Bruce: “I think she has a counselling role, to help guide him and get things thought through.”

Rachel: “Well that was the intention, that he was the one that should do the thinking and come up with ideas of what to do next.”

The testing required quite a lot of tweaking in order to create a valid test design. For instance, two different strategies were used when adding the weights to the boats. Sometimes they were added one at a time while the boat was in the water, and other times the weights would be added out of the water, and the boats would be placed in the water with the weights already in. Generally, it was discovered that the boats had issues with balancing, if the pupils had not been careful in making the boats symmetrical, and, thus, much of the test consisted of the pupils carefully placing the weights on the boat in a way that would ensure balance. It was also discovered that some boats would sink straight down when enough weight was placed on them, whereas others would tilt to the side.

4.2.3 Spinning Tops

The researchers and the group came up with a testing situation together in which the spinning top would be started three times, and, using a stopwatch on a phone, an average spin time would be calculated based on the three measurements. Hereafter, it was suggested that the group used the OCS with weight along the horizontal axis, and average spinning time along the other. The first version that was printed, was a design from a website that was not modified, whereas in all later versions the tip or the body of the spinning top were modified in different ways. The second version that was printed was slightly heavier and had a slightly longer spinning time. The group would then place the post-it’s on the OCS, and when a researcher asked how they would use this information to create version 3, Fred answered: “I am thinking more weight, even more weight, because clearly the more weight, the faster it spins. So, the more weight, the better.” This clip was shown in the review session, and here Bruce, who teaches these pupils math and science, said that he believed that the coordinate system was one of the things that helped Fred understand the relationship between weight and spin time, and that he might not have reached this conclusion without it. Bruce also mentioned that the concept of a coordinate set is something that Fred would normally have a hard time learning, but that when this concept was turned into something tangible as the relationship between weight and spinning time, he did learn it quite well. Friday, when Mick joined Fred, they worked independently and managed their own time, planning iterations ahead as well as testing the different versions without any help from the teacher. The third version was designed to be much heavier than the previous two and had an average spinning time almost twice as long as the previous versions. Thus, their hypothesis was verified through the designing and testing of the spinning tops. In the fourth version, the group
decided to add spikes on the side because they had also planned a tournament, and they believed that the spikes would help the spinning tops in a battle situation. However, even though this was the heaviest out of all four, it also had the worst average spinning time of all the spinning tops by far, thus this spinning top did not follow the previous pattern. As mentioned, the spinning tops were tested in two different ways, firstly they were tested for their average spinning time, and afterwards they were engaged in a battling tournament in which the spinning tops where pitched against each other. This was done by starting two spinning tops at the same time, in a dish where they would hit each other, and the last one standing would win the match. The researcher had suggested that the group should use a tournament style competition, pitching version one against version two, and version three against version four, and let the winners of these meet each other in a final. However, the group decided to use a structure similar to the group stage of a tournament instead, because they wanted all the spinning tops to meet each other, because they believed that it would yield results that were more interesting.

![Figure 2. Left: a picture of the Oresmian Coordinate System as it was used to design spinning tops. From left the 1st, 2nd, 3rd and 4th version can be seen. Through the first three iterations of the spinning tops, the average spinning time increased along with the weight, but, when spikes were added in the fourth version, the spinning time dropped vastly.](image)

### 4.2.4 21st Century skills

It was found that the OCS could support both knowledge construction and problem solving, when the axes where chosen according to the relevant learning objective. For the bridge and boat projects, the coordinate system was helpful in evaluating each design against each other and finding issues and ideas for improvement of the product, thus, also supporting a tinkering mind-set [6]. However, when creating the spinning top, it seemed that the nature of the OCS changed. Instead of it being merely a way of locating errors, it became a way for the group to build a theory about which factors would improve the spinning tops. When the first two models were printed, a hypothesis was formed regarding how increased weight would increase the spinning time of the spinning top, and this was tested by creating another even heavier spinning top that followed the same pattern. The pupils engaged in this activity seemed to not only construct knowledge, but also engage in what Martinez and Stager describes as engineering: “Engineering extracts principles from direct experience. It builds a bridge between intuition and the formal aspects of science by being able to better explain, and predict the world around us” [6]. Thus, it was seen that the OCS, in this case, supported the 21st century skills of problem solving and knowledge construction, but can also help the pupils move from stages of making to stages of tinkering, and even engineering [6] [11].

During the testing, it was also seen that pupils actually engaged in problem solving, especially when testing the boats. The problem solving, here, seemed to happen at two levels. One level was solving problems with the test itself, where the pupils would tweak the method to achieve valid results.
Another level was using the test as a basis for solving problems and issues with their design. The testing was also a phase where a high level of collaboration was seen. With the bridges, it was a necessity to collaborate between the groups, otherwise the testing could not be completed.

Another 21st century skill that was supported during the learning activity was self-regulation. During the initial couple of iterations, the teacher employed a degree of external regulation, telling the pupils what they should do and when to do it. However, as the day progressed forward, and the pupils got familiar with the technology and the design phases, they could plan and manage their own time. Whenever the pupils had started a print, and they had calculated the price of the bridge, they were allowed to have a break until the print was finished, and the test could start. The pupils generally managed this responsibility well. During the last two days, an even higher level of self-regulation was seen, and the pupils would not only plan their own time, but also set their own goals and work structured towards fulfilling them. This is exemplified by the group that created spinning tops, who, without much ado, planned an alternative tournament structure than the one the researcher had suggested, because they wanted all the spinning tops to meet each other. During these days, some pupils even found the lunch break highly inconvenient, as this meant the classroom had to be locked, meaning that they could not work on their designs.

Thus, we saw a very high level of four of the six 21st century skills: Problem solving, collaboration, self-regulation, and knowledge construction. The final two 21st century skills as described by Microsoft is communication and skilled use of ICT tools [11]. These two skills were not employed to a great extent during the week, however it is believed that this is rather due to the learning activity, and that the OCS can in fact support these 21st century skills if desired.

5 Conclusion

The general findings from this study all rely on qualitative action research and analysis of data from these situations. This was done mainly because of the sample used in the study, but also because the type of learning that was investigated does not necessarily measure well on predefined quantitative scales, which might be the reason why qualitative methods are most often used in research regarding maker education [5]. The initial pilot study yielded a diverse and rich source of data from which we were able to identify several barriers, but also a great deal of possibilities for the 3D printing technology in the classroom. This deep and rich understanding was used along with creative idea generation methods to envision the OCS [10]. This method helped tie the understanding achieved through the exploratory study to the researchers’ backgrounds in engineering and design, both of which contributed to this idea, which is a core aspect of the method developed by Hansen and Bryge [10]. The testing situation of the OCS was unique, since it provided an opportunity to repeat the bridge activity three times in a row, but also to use the OCS for a more free and pupil driven activity during the last two days. In general, the findings from the field study showed that the OCS would support teaching of a wide variety of 21st century skills, help avoid the keychain syndrome, and provide rich possibilities for learning.

5.1 The future of the Oresmian Coordinate system

The testing of the OCS was done in collaboration with a math teacher who was highly motivated for using it, and even stated herself in the review session that she loved the idea. This, along with the fact that the sample of pupils in this study might have been especially technology interested, does provide a certain bias. The school that the system was tested in was a school that had a special focus on sports, and included a program for talented young athletes. This is probably one of the reasons that the competitive element of the bridge project worked so well, and it should be considered whether this competitive element would work for other schools as well. These aspects produce a sampling with a variety of biases, and therefore further testing is required to understand what the OCS can add to maker education.

Testing of different age groups would provide an interesting insight into how younger pupils will be able to understand the concept of a coordinate system, and what it can add to design processes. However, it could also be interesting to test the system for older pupils who might be able to apply even more knowledge about science and math. Furthermore, the very low participation rate of girls in the field study, only 4 girls and 33 boys, means that the findings in this study is based mainly on data gathered from males [5]. Furthermore, we propose that the OCS can be used for a variety of other maker technologies, as well as in hybrid activities where more than one maker technology is used. The OCS could even be applicable to activities like chemistry or biology, activities that are not
necessarily seen as a part of maker education. We also believe that the system could be applied to a real world problem, which would entail more significance for the pupils, and this also means that the 21st century skill of problem solving as described by Microsoft would be even more profound [3] [11] [8]. The results of this study indicates that the OCS can be a strong tool for inquiry-based learning and fits well within the pedagogical roots of maker education.

ACKNOWLEDGEMENTS

We would like to thank Jeremie Pierre Gay and Thomas Overgaard for proposing this project. We would also like to thank the whole Create it REAL team for always working hard to improve their technology and providing swift solutions for technical issues. Furthermore, we would like to thank Ian Rubeck Stenz from Friskolen Skallerup for envisioning the idea of designing, printing, and testing bridges - an idea that was built heavily upon in this study. Finally, we would like to thank all the teachers who have been a part of the project: Robin Lyksholm, Alex Daniel Olesen, Hans Peter Bang Jensen, Lars Berg Kristiansen, Gitte Buus Pedersen, Søren Hausgaard Andersen, and Randi Sørensen – thank you for going above and beyond in your quest to adopt interesting technologies in your classrooms amidst your busy schedules. At last, we would like to thank Rikke Bod Lund for help with grammar and proof reading.

REFERENCES