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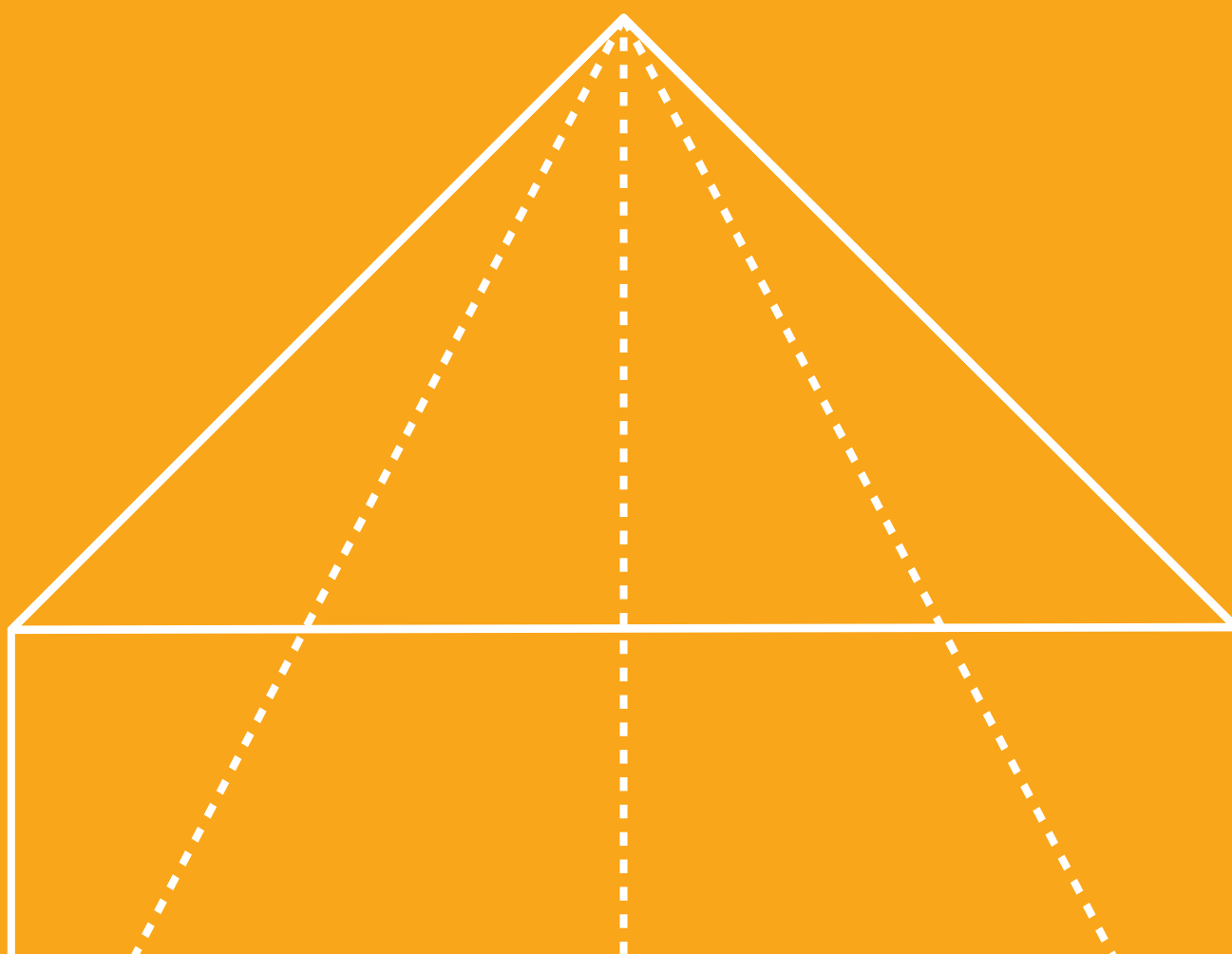
Maker education in the Netherlands – state of play and lessons for the future

maker education
leren door te maken

Maker Faire® Eindhoven

Introduction

FabLearn Netherlands invited submissions to the first FabLearn conference in the Netherlands that was held September 28, 2018, preceding Maker Faire Eindhoven September 29 and 30. This publication contains the accepted papers that were presented at the conference.

FabLearn Netherlands brought together national and international researchers, educators, designers, and makers to discuss and explore designing and making in educational contexts, digital fabrication in education, and hands-on learning for the 21st Century.

Some of the main guiding principles of the FabLearn community are the democratization of maker education, its implementation in public education systems, and a focus on constructionist learning. Submissions from both maker education and design and technology education were received.

The FabLearn Netherlands call for papers was organised jointly by Maker-Education.nl, Rotterdam University of Applied Sciences, TU Delft and Waag. FabLearn the Netherlands is a sister conference to the global FabLearn conference that has been held over the past five years at Stanford University, USA.

Index

The state of play of Maker education in the Netherlands - introduction to the research papers

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Figure 1. Girl with her penguin. Picture by Miroslava Silva Ordaz.

We are proud to organize the first FabLearn conference in the Netherlands where many maker education initiatives are shared in masterclasses and on a fair. As early as 2007, the first maker initiatives started in the Netherlands and making keeps gaining momentum in education. As new parties are embracing maker education – its teaching principles as well as the innovative making technologies – it is a good moment to make up a balance of what has been achieved so far and to discuss where maker education could go. The research papers enable us to systematically reflect on the Dutch makers education experiences.

The six papers brought together at the FabLearn Netherlands 2018 conference give a broad picture of maker education in the Netherlands. Some are written by insiders of the maker movement and others are written from the perspective of design and technology education. In this tradition, making and prototyping is seen as a crucial element and vital to the learning of young people. For a complete picture, contributions from arts education are necessary as well, however, research in this area is still scarce. The papers describe various maker initiatives in primary, secondary and higher education and in libraries, however, many of them describe initiatives in primary education. Each paper has its own focus, and together they show what has been achieved in maker

education in the Netherlands, and they highlight issues and new approaches that will forward learning through making in an even better way than before.

Make (almost) anything

The papers all stress that maker education is not just about the new innovative technologies that are used. Surely, they are an important element of the movement as they made it possible to design and build smart and useful products in a way that was not possible before. While these innovative technologies evoked a revival in making, they are usually used alongside simple materials such as carton, duct tape, wood and textiles that are equally valuable in the toolkit of the maker. All these tools together help to "make (almost) anything".

Key didactic principles: creation, iteration, sharing, and autonomy

All papers show that both learners and their teachers play important and new roles in maker education. Sharing is considered essential in making. How this is organized and facilitated by the "space" or lab is central in the articles by Peter Troxler and Manon Mostert – van der Sar on the FabLab at Rotterdam University of Applied Sciences and by Pierre Gorissen on the iXSpace in Arnhem, a Fablab for (prospective) primary school teachers and their pupils. There are key didactic principles guiding these spaces.
The initiators of the FabLab in Rotterdam show how peer learning, structured assignments, jamming and just-in-time teaching functioned in their lab. They describe how the project-based approach – starting small and building your own smart product through iterations – as a new didactic approach influenced other courses at the University. Also new initiatives such as those in the libraries and the iXspace for those involved in primary education highlight freedom for the learners and creating a maker culture. The function of the space – the stewards and the equipment – is to create a culture of innovation and trust and to create what is called a "maker mindset". The paper by Emer Beamer and Dylan Heather on the Designathon approach shows how this is done in workshops for primary school pupils in the Netherlands and elsewhere. Successes are described, talents discovered and students pursuing making in their careers.

The right kind of conflict to foster a Maker mindset

The papers are not just about successes, it is noted that learners (both students and teachers) drop out or encounter great difficulties, despite the maker movement promoting the slogan "Everybody is a Maker" and celebration of the maker mindset. This maker mindset is related to self-efficacy, motivation and interest. However, almost all papers signal that in practice this maker mindset is not always there. University students drop out during minors and primary school teachers do not feel competent as makers nor as facilitators of making. Pierre Gorissen warns that bringing devices and equipment to schools is not enough, risks surround maker education, especially as it gets momentum, and Annemarie Looijenga notices frustration and passiveness amongst pupils during making in design and technology education.
It is important to realize that people are not born as makers and that there are

dangers in the open approach of the makers education. Certainly, many pupils regain motivation because they are able to make things that are of personal interest. And yes, spontaneous peer-to-peer support while waiting for a machine eased by the informal culture is valuable. And yes, it is a positive thing to let learners deal with uncertainties and to have them iterate, this is indeed a strong element of maker education. However, a task may become too overwhelming and not doable for learners resulting in anxiety.

New answers start to come to the surface. Annemarie Looijenga argues that tasks need to be bordered to evoke the discovery behavior and the tinkering that is needed to arrive at new artefacts and insights. Making tasks must not become frustrating and put the learner in discomfort nor should these tasks be without any cognitive conflict. Learners need some cognitive conflict and to reconsider some of their ideas– a certain challenge is essential – but learners also have to perceive a task as doable. When this is not the case, they will become passive and frustrated. This insight is transferable to other educational contexts as well and might function as a lens to study how learners function in maker spaces and elsewhere. In fact, when Peter Troxler and Manon Mostert – van der Sar advise their students to start with something small when building their own smart product, this is about creating the right kind of cognitive conflict.

Peer to peer support

A strong element of maker education are the peers that are there to support each other. This is different from traditional education where – putting it bluntly – the teacher is the only supporter and expert. In maker education, peers maybe even more knowledgeable than stewards or teachers, and the line between them is blurred as they learn alongside. This requires new attitudes and competences from teachers. There is a substantial body of research (Slavin, Hurley & Chamberlain 2003) that demonstrates the extraordinary power of collaborative and cooperative learning, maker education has developed effective practices to do so. The layout of maker spaces – e.g. the free movement in the ISpace lab – and the stewards and teachers – are important. And supposedly even elements like being open during non-office hours and having a specific place on campus creates the spirit of peer-to-peer support.

Formative evaluation

Quite a number of papers address the issue of formative evaluation. A lot is learned during making. However, when the learners know where they are going and reflect on their process and their skills, more can be learned. Tom Van Eijck at the University of Applied Science in Amsterdam and his colleagues started to work with learning reports. Children filled in learning reports at the end of an afternoon in the maker space. These reports focused on some of the core learning goals in maker education such as creativity and peer-to-peer support. They showed where learners stood in the learning process and could be used to see how to proceed. Remke Klapwijk and Nadine Rodewijk are on the same page of clarifying prototyping goals through a fun to play game – in the context of open design assignments. Annemarie Looijenga repeatedly shows the need for evaluation during design and making tasks as a way to

activate pupils and adapt the challenge to the learner.

Making, Designing and Changing

It is a pleasure to notice that people from various backgrounds are visiting Fablearn and love to hear about the discoveries done by innovative teachers – and a bunch of researchers in the background – systematically observing and describing what is done and trying to explain successes and failures. All authors, implicit or explicit, merge insights from the maker movement with insights from design and technology education as well as general educational research.

The articles brought together at FabLearn Netherlands 2018 can be read as a joint evaluation of the work until now. The insights in formative evaluation are an expression of the principles of peer support and sharing of maker education and are promising for the future of maker education. The contributions can also be seen as collective endeavor to get a clearer direction and ideas for the next step: How can this sort of togetherness be created and kept alive when labs become more mainstream? How can this be realized in classrooms and libraries? Or in a maker space for primary education? How can more teachers be encouraged and enabled to adopt maker education into their repertoire of teaching practices? How can making become a meaningful approach that contributes to achieving the core objectives of primary, secondary and higher education?

We warmly invite you to read the various contributions, to get inspiration for your own practice, and to get involved in the debate.

Slavin, R.E., E.A. Hurley and A. Chamberlain, 2003. Cooperative learning and achievement: In: W.M. Reynolds & G.J. Miller (Eds), Handbook of Psychology; Educational Psychology, Vol. 7, Hoboken, NJ: Wiley, pp. 177-198.

Seven years of plenty? Learning at, with, through, from and for the FabLab at Hogeschool Rotterdam

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Figure 1: FabLab at Hogeschool Rotterdam.

ABSTRACT

Since 2011, Hogeschool Rotterdam (Rotterdam University of Applied Sciences) operates a FabLab specialized in sensing, data processing and digital fabrication. The lab acted primarily as an educational infrastructure for electives and course modules within minors, and it was a making infrastructure for students from a broad range of disciplines.

The lab also served as a breeding ground for pedagogic approaches in maker education. Its impact went beyond the lab-related courses and had a rather substantial impact on introducing maker education into educational practice within the University. The lab equally was a starting point for primary and secondary schools to learn about and begin to develop their own maker education approaches.

Many experiences were mainly shared between the people working at and for the lab. This paper brings together the scarcely and scatteredly documented experience of the seven years working on and learning about maker education through the lab. It aims to contribute to the discussion about what maker education and "fab learning" might develop into in the years to come.

Key learnings from seven years of FabLab at Hogeschool Rotterdam are primarily reflected in the design and redesign of the courses related to the lab and elsewhere in the University. Current challenges include rejuvenating the lab approach, transferring its success to new labs being established and to more general educational practices, and addressing issues of sustainability, transition and ethics.

KEYWORDS

Maker Education, Fablab, Learning through making

1 INTRODUCTION

In 2010, Fried and Torrone predicted the open source hardware market to grow beyond one million dollars [12], a market of "smart" objects that would move the interaction between humans and computers away from screen and keyboard to all sorts of interactive gadgets that could be built by everyone. At the School of Communication, Media and Information Technologies (CMI) at Hogeschool Rotterdam, it was decided to study what infrastructure would be needed to give students a place to experiment with and learn about smart objects. Particularly, the feasibility of setting up a Fab Lab at the school should be investigated.

In a somewhat bold move the then head of external relations who was also in charge of the feasibility study decided that the simplest and most powerful way to demonstrate the feasibility of a FabLab would be to build one. In spring 2011 he formed a team of internal and external experts, teachers and students of which both authors were part. Over the summer, the team developed and documented knowledge and experience on the three pillars that the lab would have to serve: (1) sensor technology for measuring and sensing all sorts of signals; (2) data gathering, processing and presentation for representing knowledge; and (3) digital fabrication technology for fabricating and making a large variety of implements – the (almost) any things a FabLab would allow to manufacture.

In autumn, the lab opened at a temporary location as part of a property guardian scheme. Experimental first university courses used the premises, we held introductory workshops for teachers and staff, and the lab took part in a number of research projects and public and university events. In summer 2012 the lab moved to its permanent location at the new premises of CMI. With this move a more structural connection between the lab and university courses, electives, minors and applied research projects was ready to evolve.

For this paper, we tried to recover the history of seven years of innovation at the lab from internal documents (such as course descriptions and course evaluations, minutes from educational design workshops), from grey literature about particular projects at the lab, and from our own memory. And we tried to relate what we did to the main theories that explicitly and implicitly informed our work, such as Vygostky's theory of the zone of proximal development [33], Piaget's constructivism [23] and Papert's constructionism [22], while being primed in "Mode 2" knowledge production [10, 21], maybe combined with a Gauntlettian belief in making as connecting [9].

2 THE LAB IN UNIVERSITY EDUCATION

2.1 The FabLab elective: What do you need to make (almost) anything

The first formal educational programme that we developed around the lab was a ten-week elective course (one session a week, 3 ECTS) entitled "What do you need to make (almost) anything" – with a nod to Neil Gershenfeld's original MIT course mas863. We did not just borrow the title of the course from mas863 (and the subsequent FabAcademy programme), also the idea of introducing one particular technology per week (laser cutting, electronics, sensors, actuators, programming, etc.), the teaching method of presenting an overview of the subject with various pointers to online resources for further study, and the overall assignment to build a smart object in the course of the elective were heavily inspired by mas863.

Using open source technologies (e.g. Arduino boards and Ultimaker 3D printers) students were building series of their own crude prototypes of smart objects, adding new technologies as the course progressed. We considered peer learning and learning from mistakes essential elements of the pedagogical approach. Therefore, we reduced net lecturing time to twenty percent maximum per session. This principle, on the one hand, only allowed us to give a brisk, top-level introduction into the topic of the week and to point students to more reference material online. On the other hand, the principle made room for student lead activity like peer review of homework and "jamming" – playfully exploring the new technologies introduced in the session. In the jamming part of the sessions we would lead students from an initial structured assignment to multiple free experiments, a pedagogical concept that later became known as I3 for "imitation, iteration, innovation" [6, 7]. We would encourage students to support each other. As teachers we would help students debug their contraptions, find additional resources online, and discuss possible improvements and extensions to their work. We were, as we used to call it, teaching "just in time" instead of "just in case".
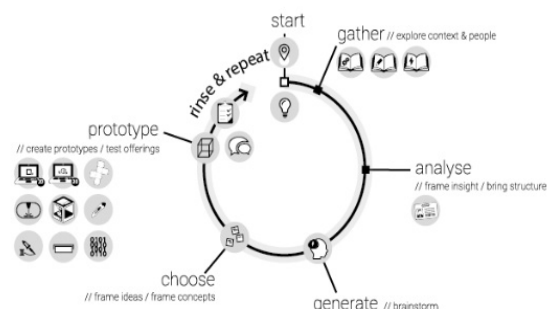

Figure 2: Teaching the FabLab elective

The course proved to be highly popular with students and teachers alike; and we had to train new teachers to teach the course. We had them take the course themselves first (including all homework) before starting to teach it. Subsequently, we organized a few follow-up meetings with those teachers to share experiences and discuss struggles. Over time, however, we noticed that particularly in terms of lecturing our twenty-percent-maximum principle was thrown overboard, and sessions reverted to more lecture type, "just in case" teaching, often combined with pre-structured test setups.

We noticed that students who followed the course invested considerably more time in this course than other courses. That also lead to a large number of students leaving the course before finishing. The students who did finish the course however created nearly professional prototypes in less than ten weeks with little to no prior knowledge of making or electronics. Students were having a hard time debugging their prototypes and learning from their mistakes. Often, we had to force students to start small and to follow an iterative process. They appeared to be used to build complex systems in a linear fashion. Even when students understood the importance of iterations and embraced its practice, they still were inclined to build that big, complex system from the beginning rather than beginning small and ironing out mistakes as they went along.

The elective kept being popular until today, and we chose to split it up in two separate electives to cut the workload. We have also started to keep the best project of each course for our archives – the student gets the material costs reimbursed or if they want to keep their prototype we have them build a second version. In the future we plan to cut the lecture time back to twenty percent again and support that with (optional) online course material and platforms.

2.2 Minor: Making for professionals

The FabLab elective proved effective to teach students to use the making and sensing technologies of the lab. And it kept attracting students. So, after this initial success we decided to develop a new, more intensive, longer and more advanced programme in the form of a minor – a twenty-week full-time programme (30 ECTS). The idea was that students from different disciplines (healthcare, product design, gaming, etc.) would develop their own ideas into concepts and working prototypes. The lab's three pillars – sensing, data, making – would become the technology drivers for innovating the students' professional practice.

In the first year we got seven students to follow the minor, coming from three different universities. As this turn-out was lower than expected, we combined the making minor with another minor – Experience Design for the Internet of Things. We worked at a self-created Smart Pop-up lab in the neighbourhood [30]. The second year we only had five students, so we combined the two minors again since there was a good fit on several topics. Again, the students worked at an outside location, situated within the context of their assignment.

Students discovered the value of making for their profession, but only a few weeks into the minor. One of the students said: "I am getting very confident in making prototypes. It is starting to become a hobby that is very relevant for my profession." Students revealed that working in a lab in the context was not only relevant but also memorable. One student said: "The minor is a good preparation on my future practice. It is a lovely mix of new technology, new ways of working, solution-based working and really an enrichment of my skills." On the other hand, students expected the minor to be more business oriented – probably due to the term "for professionals" in its name. And they told us that they experienced the minor as more focused on social interactions than they expected, which was probably a result of the combination with the experience design minor.

2.3 From minor to modules

While those students who did take the minor were very enthusiast, this enthusiasm somehow did not trickle down to the next generation of students and did not result in a higher amount of registrations, new registrations kept being disappointing. We realized that students tended (and often were encouraged) to choose minors close to their profession rather than to branch out into (yet) another specialism. At the same time, however, more and more (professional) minors asked us how they could integrate making into their programme.

We recognized that what students and faculty requested, and what we needed to do, was to change our strategy from (deep) specialisation to (broad) empowerment. To this end we decomposed the minor into twenty building blocks around making, including designing and prototyping, coding, and electronics. This allowed us to assemble various configurations for modules on "making" from short, half- or full-day workshops to two-day and full-week intensive courses.

Make Week was a programme of one week in which students learnt to make and design with digital machines such as 3D printers, laser cutters, and to integrate electronics in their projects. After this week students knew more about the maker movement and the effect of this movement on their own profession. They learnt to brainstorm about, to conceptualize, to design, and to build an interactive prototype. As we tried to stimulate a maker's approach, they had to do several iterations of the design cycle within a week. After successfully following this programme, students were able to create and use several machines on their own, and they developed a clear understanding of the possibilities of sensors and actuators as essential ingredients of a smart even interconnected Internet of Things object.

Figure 2: Building blocks of Make education.

We also designed shorter programmes, the Make Stream, Make Day and Make Workshop.

Make Stream was a condensed two-day programme in which students learnt to make and create a prototype. They were exposed to a small selection of tools and machines only. So, for example, students of the international minor "Get Connected", mainly with a background in communication, learnt how to design and code a prototype. The main goal with this group was to give them first-hand insight into the technical opportunities of making and to reduce their fear of technology in general and of coding in particular.

Make Day consisted of much shorter design cycles we encouraged students to go through. In the course of a Make Day students used only one tool or machine.

Make Workshop, as a half-day programme, could just focus on the use of one single tool or machine, essentially enabling students to work with this tool or machine on their own afterwards.

Table 1: Make Modules

	Period	Events (p.a.)	Integration	Students (p.a.)
Make Week	4-5 days	2	Completely	50
Make Stream	2 days	2	Completely	50
Make Day	1 day	4	Partly	100
Make Work-shop	½ day	6	Typically none	100

Again, students really enjoyed those programmes: "I liked it, I like making things and everything I did during this week was my first time." An interesting side-effect of the programme was the confidence students gained. "I gained a lot of confidence during this week on my prototyping skills. I did not know I was able to do all of this in just a few days" "I think it was very good to get to know every machine and technique. In the past, I never dared to use the machines because I didn't know how to use them. Now I know how to use them, so this program helped me a lot. I also really liked the way we were taught in this program." "I learnt to organize my design process better and learned to use new tools for making."

2.4 Students' use of the lab

The lab was being used by a mix of disciplines. Initially the lab was set up for the benefit of the students of the school, CMI. Yet quickly a lot of students in fashion design and product design from the nearby academy of arts were visiting our lab, probably because at the time their own labs were not easily accessible. Equally, students from industrial design, from architecture, from facility management and from healthcare technology became regular users.

Having students from very different backgrounds working in one location resulted in several unplanned transdisciplinary encounters. Students who were waiting to use a machine were always encouraged to start a conversation with the one using the machine, mostly because they could help them finish earlier so they could start themselves on their own project. This created a climate in which student always were asking "What are you doing?" and "Can you help me with ..."

2.5 Repercussions in the school and the university at large

The effect our elective and minor had on students did not go unnoticed in the School. After all, when students regularly left the elective in haste, murmuring something along the lines of "I have to go back to school", faculty could not ignore that something different was going on. And teachers who followed the elective themselves found themselves exposed to a different kind of pedagogy than what they were used to practice themselves, although the idea of establishing a less

lecture-based, more problem- or project-oriented pedagogy was of course no invention of ours at all [1, 3–5, 11, 26].

Despite the degradation of the twenty-percent-maximum principle in the elective we discussed earlier, when several programmes within CMI decided to rewrite their curriculum, practice- and project-based pedagogy became their guiding principle. In a private conversation, the then dean of the School confirmed that particularly the elective created a precedent that stimulated faculty to think differently about pedagogy and to embrace a project-based approach.

Abandoning the specialist minor "Making for Professionals" for a palette of modular interventions for a broad range of courses empowering students in "making" set the trend for a couple of other developments in the University – the move from specialist to transdisciplinary programmes, and the development of modular interventions. In 2017 the four engineering schools of the University – communication and computing, mechanical and electrical, maritime, and building and architecture – have agreed a shared vision for the year three and four of their bachelor programmes: education would be interdisciplinary, based on design thinking, and assessments based on projects rather than exams [14].

The focused approach (one theme per week) is being introduced in several minors. Besides the modules on making, similar modules are under development, for instance for design theory, business and entrepreneurship, smart industry to name a few.

3 BEYOND THE UNIVERSITY

3.1 From school outings to professional learning groups

The different approach of education brought more and more educators to our lab asking questions. We often received requests from primary and secondary schools to visit the lab with a group of students. We called these requests jokingly 'a trip to the zoo'. While in the moment empowering for the participants (see e.g. [24, 25]), those visits still fell into the keychain syndrome trap described by Blikstein [2] – kids creating a key chain hanger on the laser cutter and then seeing the laser cutter as a single purpose key chain hanger production machine. Most teachers were unfamiliar with technology and remained in the background during these workshops. The students who followed the workshops were very enthusiastic but also recognized the visit as a one-off adventure. Only a few of them came back to the lab on their own, mainly because the content was not practiced at school.

There was a need, we felt, to move beyond pseudo interventions that create "wow" effects on the spot to sustained, interwoven co-creation of curricular content with making experience. Also, as we noted earlier with our students, the idea of developing a project through iterations and working in a designerly way, would probably have to be introduced to kids at a much earlier age – we needed to start educating youngsters.

In order to do so we wanted to share our experience with educators and help them find the value of learning through making on their own. Learning through hands-on activities was regaining popularity in education, often with reference to constructivist teaching and learning methods. These developments could be linked to the global phenomenon of the maker movement and related to a more designerly approach in education. We decided to work with this design-driven understanding of research and design with teachers from secondary education.

We did not claim to hold the answer for a successful integration of making in education. We therefore decided to start a professional learning group with teachers to find answers together, in a designerly way. In this professional learning group (PLG), themed make and design, we let teachers experience the design approach in order to help them develop a corresponding educational environment into their school. The program consisted of several sessions spread over four months that included visits to different R&D labs, within and outside educational institutions. In each session we walked through a complete design cycle and participants reflected upon the visit for their own practice. Between the sessions, participants integrated new findings in their own practice and brought experiences of that back to the next session.

We started three groups over a period of five-year time. In that sense the program aimed not only at "showing" a designerly approach but in actual fact at practicing it.

Participants felt very enthusiastic by meeting mind-a-likes in these sessions and were empowered to get making in education. They also appreciated the great amount of inspiration and practical knowledge on making, like electronics, laser cutting, 3d printing but also on material and methods.

Still participants found it hard to make the link between the labs and the educational situation in class and to transform the experience at the lab into an experience for the students in class. New material was difficult to incorporate into existing courses. Also, new educational formats and insights were sometimes difficult to integrate. The program produced a large variety of ideas, yet participants were sometimes struggling to produce concrete results and to transform their findings to practical educational content. A comprehensive framework for teaching research and design did not emerge from the programme [29].

3.2 Trickling down from secondary to primary education

Over the years, more schools were discovering the possibilities of maker education and using digital workplaces as context-rich learning environments. The technique is increasingly accessible and is increasingly being introduced into the classroom.

After starting two professional learning groups in secondary education we noticed that some skills should probably be integrated in primary education. At the same time science and technology got more attention in this educational landscape. Like in other countries, strong industry lobbying lead to the government regulating that science and technology needed to be taught from primary education ("STEM is the law"). Several grants started technical programmes, mostly with promotional goals to attract more kids (and specifically girls) to technical professions. We created a plan to close the gap between our work in secondary and higher education and designed a program for primary education, together with a large (primary) school community.

We creat ed two groups in which at least two teachers per school joined, so they could work on this innovation as buddies. We used the matching characteristics of Maker Education with the (new) core objectives that primary schools got as: it builds on the natural curiosity of children, there are no winners or losers, mistakes are not a disqualification but offer feedback that makes it possible to improve your project (and learn more), content and goals are attuned to each other and are in line with daily life, projects are interdisciplinary and ambitious and helping each other is self-evident and sharing what you learn.

In the work with the teachers, we paid attention to all areas of learning (attitude to work, learning strategy, reflection etc.) while most learning in was based on trial and error, a natural feedback loop with the material. Topics such as 21st century skills and design & research learning were in line with this. Making was seen a learning style that was very natural for children. Make projects connected knowledge to reality and thereby deepened information.

During this programme teachers got acquainted with different manufacturing labs where researchers, makers and/or designers worked. In these environments, people learnt and worked in a different way than what was common in current education. Just like the programme in secondary education, this programme was set-up as a route along several labs including some FabLabs.

In the programme teachers did not only internalize the power of design (and making), but also developed new didactic and pedagogical tools that stimulate a different way of learning and that developed a start for a long-term plan for anchoring technology in education [10,11].

3.3 Beyond the university and back in

While located at the University, our lab was the first publicly accessible FabLab in Rotterdam and we had a small but regular stream of makers from the general public using our space. Often from education, they used the lab for training or bonding activities. And we served as a source of inspiration, practice and professionals for other labs starting in Rotterdam. RDM Makerspace was established in 2013 by the incubator RDM Rotterdam. Bouwkeet opened in 2016 as a makerspace at the core of an integration oriented social project. Maakplaats010 is a FabLab opened in 2018 at the city's central library.

Not all initiatives in and around our lab were equally successful. In 2014 we aimed high with the bid "roffab" (from "Roffa", urban slang for Rotterdam) to establish some 30 educational makerspaces in Rotterdam together with other local maker initiatives over a period of three years with an investment of 1,7 million Euro which would have come from a citizen initiative fund. However, the plan did not resonate with the jury and was not shortlisted for the public vote that had to decide the final fate of the six highest ranking bids.

We sometimes got questions if people from the outside could join our courses, for example, the FabLab elective. When we started the lab, the university had an office that marketed university activities to third parties. Thus, in theory, we could have opened the lab for commercial trainings and activities. Yet our priority were our own students, and we did not often use this facility. Also, we did not have the capacity (and did not feel the need) to actively recruit individual participants so we could fill a (commercial) course. The commercial office has since been closed down, and we reverted to organizing events together with other networks in the city, like for example Broedplaats010, a course for educational innovation.

Teachers, rather, started their own initiatives to grapple with maker education. MeetUp 010 begun in 2015 as a Rotterdam based network of primary and secondary school teachers who regularly hold meetings around the topic. For arts teachers the conference and training event "Make!" started in 2017.

Back at University, "learning though making" developed into a shared interest between a group of researchers and educators from different schools (art, CMI, education) [15]. By visiting each other's practices, the participants investigated how education in labs, communities and stations (the term for labs used at the arts school) could be developed and improved using participation, co-creation peer-review between students and teachers. We followed up and deepened the discussion on assessments, testing and monitoring in rich contextual learning environments [16].

4 DOCUMENTING, DISSEMINATING, AND DEVELOPING

4.1 Trying to capture what we got

It is a pretty well known fact that both makers and educators are notorious for not – or insufficiently – sharing their work with others. Despite having researched (and "proven") that ourselves [34], we were not really any better at documenting and sharing – nor were our students.

In keeping with good practice from years of knowledge management we started off documenting particularly the making and sensing technologies of the lab on a wiki. We used the same platform to also keep track of the development of the lab. And while this knowledgebase is not really widely used – neither in the lab nor more broadly in the University – there is a small number of core staff related to the lab who keep using and updating the wiki on a regular basis.

As we were aware of the documentation issue when introducing the elective, we made it mandatory that students would keep some kind of diary of their activities, writing down their ideas, decisions, contraptions, trials, failures and reflections. While warmly suggesting using the wiki as a place to do that, we initially left the format open to the students as long as they handed in their work via the e-learning platform we were using at that time. Some students indeed kept a week-by-week diary, while others produced a retrospective documentation in the final week, and others reverted to just fulfilling minimal requirements, handing in a few photos.

At one point, two colleagues of ours who had been teaching the elective for some time experimented with a new format – they required students to document their projects on the public platform Instructables [27]. This move appeared to have an extra motivational effect on students. As Instructables is a public platform, suddenly the students' projects were exposed to the potentially vast audience of more than 30 million unique users [13]. So, the projects were very likely to pick up some interest and comments from a few users. This appeared to motivate students to update and improve their own instructable while the course lasted. Unfortunately, when the elective was handed down to the next group of teachers, this little piece of wisdom (or good practice) got lost in transition and was forgotten.

We were also thinking and experimenting on capturing all fabbing activity that took place in the lab. Based on the documentation station developed at Protospace in Utrecht [17], we set up a series of student projects to replicate such a station at the lab – without much success. The problems were twofold: lab users were hesitant to use the station to document their work; and the series of student development projects never really delivered a system that was working properly. The only element that we eventually were able to implement was a simple registration kiosk where lab users would have to identify themselves before using the lab.

This system gave us some tally on the population of the labs' users but fell short of capturing the actual use of the lab and what is made there. Currently a student in Communication and Multimedia Design is creating a visual interface for the touch table in the lab where we demonstrate projects that are created in the lab.

4.2 Present, post, publish

Occasionally, we shared some of our experiences with wider audiences through presentations at academic conferences [19] [20], [29], we have given many talks and presentations to mainly practitioner audiences, and we have received numerous visitors to the lab who asked us to share our experiences with them.

Apart from the conference papers, little of this sharing has left any notable traces. At least for the professional learning groups (PLGs) we tried to capture the experience in various booklets and video clips, often in collaboration with the participants, producing a small body of gray literature (e.g. [28], [31], [32]) and video [18] as we went along.

We contributed with some of our thoughts to the FabTables, the (ir)regular meetings of the Dutch FabLab community, we posted some creations on Instructables, and we shared projects on Facebook and Instagram – but not as thoroughly as we might have wanted.

4.3 People

Probably the most effective way of sharing projects and experience in the lab was between people. We mentioned the mutual support and transdisciplinary inspirations already. Even more important to collecting and preserving knowledge at the lab were lab staff – the lab manager and the lab assistants which we called "stewards".

Stewards were students we hired to help lab users with the machines. From the beginning we installed a system that put the stewards in charge of the lab. There were a few rules in place, for instance every steward was required to work at least 16 hours per month, to contribute to the lab with their talent (for example by writing a tutorial or building an app), to actively share their knowledge with the other stewards which we facilitated with physical log books and sharing nights with beer and pizza.

We also made stewards the real owners of the lab. They were in charge of the planning of their shifts. And they were the ones sitting on the hiring committee when we had to attract new stewards. So, while we required only one steward per shift to be present for helping users, most of the time many of other stewards gathered at the lab as well. In their own words, 'the atmosphere is just nice'. The stewards were the ones making space, making

place at the lab, with the lead of the lab manager. His task was of course to handle the more difficult problems, to keep track of stack, of larger projects and to liaise with the rest of the organisation and with suppliers and partners.

Figure 3: Meeting of staff and stewards at the lab.

The great atmosphere in the lab and the strong connection between stewards were the result of the work and attitude of our first lab manager, Arnold Roosch, whom we unfortunately lost last year in his fight against cancer. As one of the founders of the lab, he was the one who made the lab organize and feel like it did. Not only knew he how to fix probably anything – or knew how find a way to do so –, he also encouraged students and teachers to "break the rules, forgive quickly and never regret anything that made them smile".

The mix of disciplines in the lab, has created several unlikely projects over the years. For example, a student of computer science met a fashion designer, and together they created smart clothes that reacted to the feelings of the wearer, before anyone heard of that opportunity before [8].

Even more impressive is the number of companies risen from our steward pool. They would not have met without this lab. One group of stewards founded WeUmbrella, who developed Living Light. Living Light is an atmospheric lamp that harvests its energy from a plant living inside the lamp, harvesting plant microbial energy. Another group of stewards founded Vogelnest, a pop-up shop were several designers came together and created new products from friendship and shared passion.

In an attempt to capture more of the impact we had, we just finished collecting these stories to share the hidden wealth created through the lab.

5   REFLECTION AND DISCUSSION

At the FabLab at Hogeschool Rotterdam, we have been practicing maker education and fab learning for seven years now. Where those the seven years of plenty or the seven years of famine? And if those were the seven years of plenty, as we are likely to conclude, have we acted wisely as Joseph would have done, saved what we had abundantly?

We have formally taught several thousand students in our electives, minors and make modules. We have spoken to hundreds of makers, educators and fabbing enthusiasts. We have had hundreds of school kids visiting the lab. We have led dozens of primary and secondary teachers to experiencing a maker approach to education. We have seen dozens of stewards caring for the lab and for the thousands of users who came to work at the lab, producing numerous crazy contraptions and some mind-blowing bachelor projects. We have produced videos, posters, slide decks and papers, given presentations and held keynote speeches. We have seen two companies emerge from the lab. Indeed, in terms of numbers we would see those seven years of plenty.

5.1   Lessons learnt

We learnt what to include in our courses and modules and what to leave out. For instance, we initially thought it imperative to include a session on machine-to-machine communication in the elective, but quickly scrapped that based on the students' evaluation. We learnt how to tailor the elective better to the interests of students by splitting it into a "making" and an "electronics" version. We learnt to design and deliver focused timeboxes of maker education in the form of the make week, stream, day and workshop.

We learnt how to implement a designerly approach into maker education. We figured out how to teach students to work in iterations – try, rinse and repeat – by doing this ourselves. We figured out, at least for the two of us, how to educate in the unknown where the teacher acts as a guide to knowledge, debugging contraptions, rather than as the source of it, the omniscient expert.

Through working and teaching in the lab we confirmed our understanding that technology is a means, not an end. And we experienced that, apparently, teaching habits of individuals are stronger and stickier than what we thought was a "good concept". And yet we failed at recognizing that in time to steer colleagues clear from old routines.

We, and our colleagues at the University, learnt from our practice about the powers and the limitations of problem- and project-based education. Had it not been for the lab, the new curricula at CMI had maybe not embraced that very idea as their core educational principle. Still, these curricula needed their own iterations to become smooth as programmes. Outside university, some of the primary and secondary school teachers we worked with got the point of maker education. Other labs took inspiration from our way of organizing the lab.

5.2   Critical success factors

A number of factors contributed to the success of the lab in those seven years. We believe the most important factor is the people who work in the lab – the lab manager, the stewards, the teachers. It certainly helped that many of them stayed with the

lab for many years which created continuity and stability.

Related is a second factor: an understanding of collective, shared ownership of the lab by the people who work there. This ownership manifested itself in the high availability of the lab equipment thanks to a low breakdown rate, and in the clever hacks and "little helpers" people developed – from instructional posters and samples of engraving settings for the laser cutter to filament racks for 3D printers.

The environment of the school contributed greatly to the success of the lab. We experienced little pressure from management to justify the lab or the acquisition of new tools and equipment, or to monitor and report in detail about occupancy levels, student throughput and internal and external impact. We were never forced to carry out extensive risk assessments. Middle management did not interfere with how the lab managers organized their crew.

5.3   Recommendations

As lessons to keep and tell we take away the idea of having a good story to start with – such as the "lab to build smart object" or the activities of "sensing, data processing, making". We believe that such a story helps to clarify the purpose of the lab. We are currently trying to transfer this approach to the University's "smart port lab" and to a new lab dedicated to omnichannel retail, the "phy-gital lab".

Also, we believe that the atmosphere of the lab, the way "we go about our things", is a key ingredient to develop in those new labs: collective ownership, mutual trust, a feeling of "us" among the crew. This is largely a leadership concern, and various elements of "sharing" contribute – the sharing of interests and values on one side, and the sharing of news, experiences, knowledge and concerns on the other side.

Finally, we would recommend a "designerly" – or agile – approach to the development of the lab which we see as continuous development or "permanent beta". This approach relies on solving problems just in time, instead of just in case, combined with an attitude that replaces fear of failure with acceptance of mistakes and a drive to learn and improve. This approach also relies on a belief that any first solution does not need to be perfect but can be improved by iteration and "rinse and repeat".

5.4   The way forward

There is another reason why we think those were the seven years of plenty: we were fresh, young, curious ourselves, new to the University and thus spawning interest. Seven years later, we are at risk of becoming just another part of the University that appears to always have been there. We strongly feel that we need to challenge ourselves again, to find a way to rejuvenate the lab. This becomes even more of concern as many elements that made us unique in the beginning – the Arduinos and the 3D printers, the hands-on learning through making approach – have in the meantime found their place as a regular ingredient in many university programmes, as faculties have upgraded their infrastructure and changed their curricula.

Adding to those challenges we already are facing, the current pool of stewards appears not to be as engaged as the first group. We can only speculate that they might have felt more ownership of the lab when we were located outside official university buildings. At that location we were free to open the lab 24 hours a day. Today we can only open the lab when during university opening times.

While those seven years of plenty have surely left numerous traces, we have not sufficiently collected and stored them, and not very explicitly so. So, are we expecting the next seven years to be the years of famine? Certainly, we don't want to let that become a self-fulfilling prophecy. Hard work will be needed, and more research is underway.

We are currently redeveloping the lab, seeking to reinject that fire of the new and curious. Collaborating and co-creating with the "smart port lab" and the "phy-gital lab", we hope, will create enough momentum to launch on a new wave of educational renewal. Instrumental (but not formative) will be to embrace new technologies such as artificial intelligence, blockchain, autonomous systems, and co-bots. And we believe that being able to talk and write about work and projects in the lab needs more attention.

We are explicitly focusing on the role teachers play in a lab setting, too, something we only addressed rather implicitly until now. One line of research focuses on "educational mishaps" and the way teachers are embracing the opportunity to discover the unknown, allowing themselves to make mistakes, and learning from them. We hope to empower more teachers to approach teaching in a designerly way, shifting their paradigm of teaching from being omniscient masters to begin designers of learning and knowledge co-construction.

Last, not least, a colleague is joining us who is particularly interested in teaching for sustainability and transition. She is studying the design of pedagogy, curricula and organization of such courses, particularly looking at how these can contribute to students becoming responsible and responsive innovators, who would be well equipped to face the wicked, ill-defined problems of sustainability. This research will strengthen our stand on technology as a means, not an end, and it will help us to address the ethical issues of emerging technologies which we blissfully ignored almost completely in the lab so far – except maybe for the blip of the Liberator scare

ACKNOWLEDGMENTS

REFERENCES

[1] Barrows, H.S. 2006. Problem-based learning in medicine and beyond: A brief overview. New Directions for Teaching and Learning. 1996, 68 (Aug. 2006), 3–12. DOI:https://doi.org/10.1002/tl.37219966804.

[2] Blikstein, P. 2013. Digital Fabrication and 'Making' in Education: The The Democratization of Invention. FabLabs: Of Machines, Makers and Inventors. Transcript Publishers. 203–221.

[3] Blumenfeld, P.C., Soloway, E., Marx, R.W., Krajcik, J.S., Guzdial, M. and Palincsar, A. 1991. Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. Educational Psychologist. 26, 3/4 (Summer/Fall 1991), 369.

[4] Boud, D. and Feletti, G. 1998. The Challenge of Problem-based Learning. Psychology Press.

[5] Duch, B.J., Groh, S.E. and Allen, D.E. 2001. The power of problem-based learning: a practical "how to" for teaching undergraduate courses in any discipline. Stylus Publishing.

[6] El-Zanfaly, D. 2018. [I3] Imitation, Iteration and Improvisation: Embodied Interaction in Computational Making and Learning. Massachusetts Institute of Technology.

[7] El-Zanfaly, D. 2015. [I3] Imitation, Iteration and Improvisation: Embodied interaction in making and learning. Design Studies. 41, (Nov. 2015), 79–109. DOI:https://doi.org/10.1016/j.destud.2015.09.002.

[8] Fashion on Brainwaves: 2015. https://www.hogeschoolrotterdam.nl/samenwerking/samenwerkingsportfolio/showcase/fashion-on-brainwaves/644/. Accessed: 2018-07-06.

[9] Gauntlett, D. 2011. Making is Connecting. The social meaning of creativity, from DIY and knitting to YouTube and Web 2.0. polity.

[10] Gibbons, M., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M.A. 1994. The new production of knowledge: the dynamics of science and research in contemporary societies. SAGE Publications.

[11] Hye-Jung Lee and Cheolil Lim 2012. Peer Evaluation in Blended Team Project-Based Learning: What Do Students Find Important? Journal of Educational Technology & Society. 15, 4 (Oct. 2012), 214–224.

[12] adafruit industries, adafruit 2010. Open source hardware $1m and beyond - foo camp east 2010.

[13] Instructables.com is Celebrating 30 Million Unique Users! 2015. http://www.instructables.com/topics/Instructablescom-is-Celebrating-30-Million-Unique-/. Accessed: 2018-07-01.

[14] Joosten, K., Brink, W. van den, Bosch, M. van den, Elferink, H., Maas, H., Ogtrop, M. van and Voorbij, L. 2017. Visie op Techniekonderwijs. Ambitie techniekopleidingen Hogeschool Rotterdam.

[15] learningthroughmaking: https://learningthroughmaking.wordpress.com/. Accessed: 2018-07-06.

[16] Linden, L. van der 2017. Verslag Verdieping: Toetsing en assessments. learningthroughmaking. https://learningthroughmaking.wordpress.com/verslag-verdieping-toetsing-en-assessments/. Accessed: 2018-07-06.

[17] Määttää, A. and Troxler, P. 2011. Developing open & distributed tools for Fablab project documentation. OKCon 2011 (Berlin, Jun. 2011).

[18] Mostert - van der Sar, M. 2016. Het Leerkracht Ontwikkelteam. Vimeo. https://vimeo.com/151116532. Accessed: 2018-07-06.

[19] Mostert - van der Sar, M., Mulder, I.J., Remijn, L. and Troxler, P. 2013. Fablabs in design education. (Dublin, Sep. 2013).

[20] Mostert, M., Mulder, I., Remijn, L. and Troxler, P. 2013. Opportunities for Design Education? FabLabCon 2013: The First European Fab Lab Conference (Aachen, Sep. 2013).

[21] Nowotny, H., Scott, P. and Gibbons, M. 2007. Re-thinking science: knowledge and the public in an age of uncertainty. Polity.

[22] Papert, S. and Harel, I. 1991. Constructionism. Ablex Publishing Corporation.

[23] Piaget, J. 1973. To Understand Is To Invent. Grossman.

[24] Pucci, E.L. 2014. Ik ben ster(k). Empowering Young Adults, a Peer-to-Peer Talent Development Platform. Proceedings fo the Fab 10 Academic and Research Colloquium (Barcelona, Jun. 2014).

[25] Pucci, E.L. and Mulder, I. 2015. Star(t) to Shine: Unlocking Hidden Talents Through

Sharing and Making. Distributed, Ambient, and Pervasive Interactions. Springer Science $\mathplus$ Business Media. 85–96.

[26] Strobel, J. and Barneveld, A. van 2009. When is PBL More Effective? A Meta-synthesis of Meta-analyses Comparing PBL to Conventional Classrooms. Interdisciplinary Journal of Problem-Based Learning. 3, 1 (Mar. 2009). DOI:https://doi.org/10.7771/1541-5015.1046.

[27] Teach Students to Make Things by Making Them Write Instructables: 2017. http://www.instructables.com/id/Teach-Students-to-Make-Things-by-Making-Them-Write/. Accessed: 2018-07-01.

[28] Troxler, P., Mostert-van der Sar, M., Roosch, A., Prins, J., Mulder, G., van der Steen-Zijlstra, H., Roukens, S., Verburg, A., Vaas, M., Bos, A. and Ferrari, F.J. 2016. Make & Design. Opbrengsten DocentOntwikkelTeam Professionele Leergemeenschap Make & Design. Kenniscentrum Creating010, Hogeschool Rotterdam. https://issuu.com/manonvandersar/docs/dot_make_design_2015_finalweb. Accessed: 2018-07-06.

[29] Troxler, P., de With, E. and Mostert - van der Sar, M. 2014. DOT O&O. Developing Research and Design Skills in the Classroom (Dutch secondary education). FabLearn Europe (Aarhus, Jun. 2014).

[30] Van Waart, P., Visser, E. and Harbers, M. 2015. How to Design for Diversity in Smart Cities? (2015).

[31] Verbakel, E., Troxler, P. and Mostert-van der Sar, M. 2015. Leerkracht Ontwikkel Team (LOT). Wetenschap & Techniek in het basisonderwijs (2015). Kenniscentrum Creating010, Hogeschool Rotterdam. https://issuu.com/manonvandersar/docs/boek_compleet. Accessed: 2018-07-06.

[32] Verbakel, E., Troxler, P., Mostert-van der Sar, M. and Doveren, T. van 2016. Leerkracht Ontwikkel Team (LOT). Wetenschap & Techniek in het basisonderwijs (2016). Kenniscentrum Creating010, Hogeschool Rotterdam. https://issuu.com/manonvandersar/docs/lot_interactief__digitaal_. Accessed: 2018-07-06.

[33] Vygotsky, L.S. 1978. Mind in Society: The Development of Higher Psychological Processes. Harvard University Press.

[34] Wolf, P., Troxler, P., Kocher, P.-Y., Harboe, J. and Gaudenz, U. 2014. Sharing is sparing: open knowledge sharing in Fab Labs. Journal of Peer Production. 5, (2014). http://peerproduction.net/issues/issue-5-shared-machine-shops/peer-reviewed-articles/sharing-is-sparing-open-knowledge-sharing-in-fab-labs/. Accessed: 2018-07-06.

Collaborating on maker education in primary education: iXspace

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SUMMARY

The iXspace is a space for maker education, located both in Arnhem and in Nijmegen. It is part of the iXperium / Center of Expertise Teaching and Learning with ICT (iXperium / CoE). The goal of the iXperium / CoE is the professionalization of both teachers and (prospective) teachers in primary, secondary, vocational and higher education and of knowledge creation in the domain of learning and teaching with ICT. Together with the partners within primary education a need for more support of maker education wzas identified. This led to the creation of the iXspace. The iXspace is not just a physical environment. It is also a virtual hub, a meeting place where parties with various background (education, research, innovation, technology, creative) come together to learn and share knowledge. This paper describes the underlying vision and background of the iXspace, and current research related to the iXspace.

KEYWORDS

Maker education, iXspace, Science and Technology, Primary education

1. BACKGROUND AND VISION

The iXperium/Centre of Expertise Teaching and Learning with ICT (iXperium / CoE) is a collaboration between HAN University of Applied Sciences (its Colleges of Education for Primary and Secondary School Teachers and its Research Centre for Quality of Learning) and primary, secondary and vocational education, mainly located in the Arnhem and Nijmegen region. This collaboration aims to enhance personalized education through ICT and to develop digital literacy. The focus is stimulating and facilitating the professional development of pre- and in-service teachers. The iXperium / CoE is a network organization that welcomes a growing number of partners from diverse fields, such as education, science and media design.

Within primary education in the Netherlands, schools have committed themselves to introduce more science and technology into their curriculum [11,27]. This coincides with worldwide growing interest in the idea of (re-)introducing the concept of making or learning by doing into education. The term maker movement was first coined by Dale Dougherty of O'Reilly Media in 2005 who not only launched Make magazine, a quarterly journal about DIY projects, but also, in 2006, a nationwide series of Maker Faires that became the first showcases for the emerging movement [3]. It can be described as a community of hobbyists, tinkerers, engineers, hackers, and artists who creatively design and build projects for both playful and useful ends. There is growing interest among educators in bringing making into education to enhance opportunities to engage students in the practices of STEAM (Science, Technology, Engineering, Arts and Math) within education [17,30,32,33].

There is no set definition for what making is. Martin [17] describes it as: "a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a 'product' of some sort that can be used, interacted with, or demonstrated". Within that definition, making can often involve a mix of traditional craft and

hobby techniques (e.g., sewing, woodworking, etc.) and digital technologies. They can be used either for manufacturing (e.g., laser cutters, CNC machines, 3D printers) or be applied as part of the design (e.g., microcontrollers, LEDs).

Already in the sixties of the last century, the American cognitive psychologist Jérôme Bruner argued that it is more important for children to understand underlying conceptual structures than to remember separate facts [5]. He said: Give a child a problem

or problems and by nature the child will want to go to research. Within the research process a child will learn to look critically at what is relevant to find out the "truth" [8]. But the child will also learn other necessary skills that we now often describe as 21st century skills [28,31]. Seymour Papert [19,20], who was already active in the 1960s with programming and robots in education, introduced the concept of constructionism or "learning-by-making". Papert, like Piaget before him, had emphasized on the incremental construction of knowledge. Where Piaget focused on the cognitive process whereby the learner is enabled to view the world in larger abstractions, Papert emphasizes the connection between the physical and becoming one with the object of research [2]. Creating is a skill that society and the labor market increasingly presupposes that people possess, but which is not necessarily present and must therefore be taught [21]. Maker education can contribute to this.

The primary education partners within the iXperium / CoE identified that a lot of the challenges faced by teachers while introducing science and technology or maker education are similar, although maybe not completely identical, to the ones already in the focus of the iXperium / CoE. And so the idea of the iXspace, a maker space for maker education as part of the iXperium / CoE was born. For now the iXspace focusses on maker education in primary education, meaning that schools for primary education and teacher trainers and students of the HAN College of Education for Primary School Teachers (HAN Pabo) are amongst its main users. But in the future this the other educational sectors involved in the network.

The vision statement of the iXperium/CoE states: "*In the future, learning is life-long personalized learning in a technology supported social learning environment*" [15]. The iXspace is such a social learning environment where the aim is to inspire teachers and teacher trainers for maker education, challenging them and encouraging them to implement design based education. The education that they design should enable students and student teachers to develop their 21st century skills or enable them to create education that enables those developments.

2. METHOD AND DESIGN

There is no fixed recipe that describes how a makerspace in education should be designed.
The iXspace in Arnhem and Nijmegen are not identical with regards to available resources. Both have a stock of basic materials to build with like cardboard, wood, rope, glue, tape, glue guns, scissors, cutting knives and basic electronics like micro:bit, Arduino, servo's, small electro motors, wires, sensors, batteries and battery holders, mini solar panels for small cars etc. There are also

some bigger machines available like 3D-printers, a vinyl cutter (Arnhem), a laser cutter (Nijmegen). In general the bigger machines turn out to be both expensive, require specialized support and are more difficult to use with bigger groups of students. So, the emphasize currently is more on making sure that the stock of (small) components and consumables is big enough.

Designing a makerspace for education however entails more than just purchasing a number of devices [13,23]. The main design principles used when setting up the iXspace were:
- *Freedom of movement*; this is a central principle at the iXspace. It entails not only the possibility to walk in and out whenever you want, but also the ability to "move the room". To this end, the furniture is as much as possible, easily movable;
- *Open and available*; the iXspace is available when the iXperium is open. It is possible to reserve the space, but then also in principle it is possible for people to "walk-in";
- *Free use*; as far as possible, materials, tools, (small) components and consumables are available for participants free of charge; exceptions are more expensive electronic components such as Arduino's, Micro:bits and more expensive sensors that are made available at cost price or components that can only be used temporarily, such as the LEGO components;

Material rack in iXspace Arnhem

- *Didactic use of the space / materials is key*; the iXspace is not a competitor of other workspaces like the Fablab, which in Arnhem is also available as part of the HAN. It also doesn't market itself for generic use, but always links use of the iXspace to educational purposes;
- *Mix of tools*; A space for maker education is more than just a number of 3D printers and

laser cutters. This also applies to the iXspace. Although there are 3D printers and a large stock of electronics and ict components for making, there are also sewing machines, fabrics, paper, cardboard, scissors, paint, everything that can help in the realization of the products and the support of the creative process.

- *Learning by doing;* This principle does not only apply to the teachers and students who come to the iXspace, but also to the iXspace itself: it is a space that is evolving, based on the experiences of users and based on research.
- *Support is demand*-driven; the iXspace had coaches that can support users while they are active in the iXspace. How much support is given depends on their indicated needs.

Because of these principles, the iXspace is organized in such a way that participants can start working on their own research questions, but it can also be used for professional development or as part of the regular courses of the HAN Pabo.

The walls of the iXspace are either of glass or of walls that can be provided with more or less temporary posters, examples of (partial) products etc. or that can be used for brainstorming sessions. Opening times are similar to the rest of the building, this means the iXspace is closed during the weekend.

iXspace Nijmegen

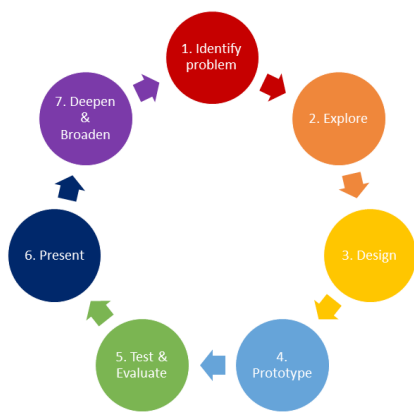## 3. THE RESEARCH AND DESIGN CYCLE

The activities within the iXspace follow a 7-step division of research and design based learning [7,10]. See also the image of the cycle below.

The seven steps of the research and design cycle are:

1. *Identify the problem;* what is the problem, who are involved, what general requirements are there for a solution?

2. *Explore and research the problem;* what are possible (directions for) solutions, collect ideas, experiences, existing research;

3. *Design;* sketch a design for a possible solution; describe suggested material use;

4. *Prototype;* build a prototype based on the design;

5. *Test and evaluate;* test the prototype with the end-users, evaluate the design; describe possible options for improvement;

6. *Present;* present the results of the design cycle to others; collect feedback;

7. *Deepen & broaden;* reflect on the problem and the previous steps; explain why things worked or failed; what would you do different next time?

Research and design based learning

There are other divisions possible where the activities are split in less or different steps, see for example Suchman [26], Llewellyn [16] or Smith, Iversen & Hjorth [25]. We choose to follow the 7-step approach, because it aligns best with approaches already used in primary education in the Netherlands in particular within science and technology topics. We did not split research and design into two separate (linked) cycles like is done by SLO [24] and some others, because we see them as integral parts of a research through design cycle [25].

The use of the research and design cycle within the iXspace is two-fold: on the one hand it is the base for learning activities designed by teachers in the iXspace. But it is also the method used by the teachers to design those learning activities

In general, two types of usage scenarios can be distinguished within the iXspace:
1) Use that originates bottom-up; teachers have a question, problem or desire for professionalization;
2) Use that originates top-down; for example, because a school board decides to start working with creative education and wants to professionalize teachers, or to train together.

Both usage scenarios are supported. Below are some examples of the use of the iXspace. This list is not exhaustive but illustrative:
• A teacher trainer from the HAN Pabo provides an assignment to Pabo students where the students learn to design a product for a problem. In this case the Pabo students work together with students from Hogeschool Artez. The students carry out the assignment in the iXspace , supported by both the teacher trainer and the iXperium coaches.
• A group of teachers from a school for primary education visit the iXspace to go through the 7 steps of the research and design cycle during an single afternoon. Prior to the visit, the iXperium discussed the topic of the assignment. The purpose of the visit is to experience the maker

education and to think about the way in which the group can apply this within their own school.
• A teacher from a school for primary education has made a lesson design according to the 7 steps of the research and design learning; the teacher visits the iXspace with her class to perform the lesson design.
• A design team consisting of teachers from a school for primary education, a teacher trainer from the HAN Pabo, a researcher and an expert in ict and learning work together in the iXspace on a learning arrangement for students of a course where they learn to use the 7 steps of designing.

During the first year of active use of the iXspace, it showed that primary school teachers, but also the teacher trainers at the HAN Pabo, find it challenging to design education that incorporates maker education using the research and design cycle. They are not used to developing learning material that adheres to the research and design based cycle. But more importantly, they are not used to working this way themselves. This is not a problem limited to the iXspace but is more generally felt in (primary) education in the Netherlands [6]. As a result of this, it was difficult to get a broad group of teachers and (prospective) teachers into the iXspace. Mostly already reasonably experienced makers found their way to the iXspace.

4. RESEARCH PROJECT

In an effort to facilitate a broader uptake of maker education within the schools for primary education within the consortium and to improve the support of teachers through the iXspace, a research project was started in 2017. In this project, teachers from primary education, teacher trainers from the HAN Pabo, the iXspace coaches and researchers from the iXperium / CoE collaborate on the topic of how to design maker education within primary education. The schools in the consortium wish to integrate the introduction of maker education with the implementation of science & technology like agreed in the Dutch National Technology Pact [27]. They not only look at what it should look like, but also what pedagogical and didactic requirements this has for teachers and what support teachers need.

In phase 1, the project group researched how maker education is currently being designed and implemented in the Netherlands. During visits to a number of makerspaces, the team discussed the design principles, methods of operation, vision and methodology with the people responsible for the spaces. The makerspaces that have been visited each have their own approach: fully integrated in an educational program, as an independent makerspace outside of education or even consciously outside all regular institutions

and regulations. Combinations of this also occur, resulting in spaces were in addition to programs in close collaboration with schools, independent space is offered to (young) makers.

After combining the results of the visits with design principles of maker education from the studied literature [12–14,22,29], a number of common maker education related didactical and pedagogical concepts were identified:

- Maker education usually starts with a research question or design question that is relevant to the students or that is formulated by the students themselves;

- Students do not always ask that question automatically but must often be encouraged to formulate questions, to make a plan and to take action;

- In maker education, learning often is achieved when pupils try things out and discover the effects of things through the process of deconstruction, construction and prototyping;

- This learning preferably takes place together with others, from others, to others, both inside and outside the boundaries of the school;

- The supervisors of maker education (the teachers) are expected to be enthusiastic makers themselves, who also continue to learn (also from the students);

- Apprenticeship requires technical skills, such as being able to operate machines or knowledge of material processing;

- These technical skills must be taught and learned as soon as there is a need for it;

- ICT and digital tools are an integral part of the tools used in creative education, for example via the use of 3D printers and programmable parts like the Micro:bit, Arduino, servos;

- Learners should be allowed to make mistakes and learn how to deal with setbacks. There must be time and space to make mistakes and to learn from them.

During a design session with teachers in phase 1 and from the literature studied, it became clear again that many teachers do not feel competent as creators or to supervise maker education. Teachers are not used to showing that they also have to learn. They do not always find it easy to switch between the role of expert and supervisor at the right time [9]. But also not all students are born creators or are used to conceiving and realizing creative solutions [4,18]. They don't always have the attributes that are part of the maker mindset. Martin [17] describes these as: playfulness, asset- and growth-orientation, failure-positive, collaborative. Because of this, it is often unclear to teachers what support they have to offer the various students in maker education. Teachers request more concrete pedagogical and pedagogical help.

In phase 2 of the research project, the teachers, supported by teacher trainers and the iXperium coaches, will therefore start to design learning activities for maker education using the research and design cycle. While going through the cycle, a support and training plan for teachers is being developed, based on their needs. The involved teachers have different background and experience in maker education, not all of them al experience. Also, during phase 2, they will collaborate with other teachers within their school to broaden the reach of the results. The cycle will be completed twice, where learning activities will be designed, tested and evaluated, improved, tested and evaluated again. After the first and second cycle the results will be presented to colleagues, peers, experts, researchers and other interested parties. They will be asked to give feedback and act as critical friends [1].

Researchers will observe the test runs of the learning activities and interview both teachers and students with regards to the designed activities. Did the activities achieve the formulated goals, do the students recognize themselves in the described goals and targets?

All results and developed learning activities will be shared under a creative commons license.

5. CONCLUSIONS AND FOLLOW-UP

In the Netherlands a growing number of parties, both within primary education and outside of the regular organizations, are busy implementing maker spaces and maker education. There are differences in their goals and design principles. Some feel think that the maker movement and education cannot be combined, others take a more nuanced view, but the challenges that they see, are real. Teachers and students do not always find it easy to take their "new" roles in maker education. Neither teachers or students are automatically born with a maker mindset. Some experts point at the history of computers in classrooms as a warning for what could happen with maker education [17]. In the past, many policy documents tacitly assumed that the computers themselves were change agents and that their mere presence within a school was enough to bring change and innovation to the learning an teaching process. The same risks surround maker education. Just having devices or even a maker space in a school is not enough. Of course, the infrastructure needs to be there, but more importantly teachers need to have to have the didactical and pedagogical tools to guide students into becoming makers. There needs to be a community to support both teachers

and students. And we need more research to show them what works and what doesn't.

The iXspace aims to grow into the social learning environment that can provide that community and support, backed-up by research.

6. ACKNOWLEDGMENTS

REFERENCES

[1]   Erica Aalsma en Frans Jansen. 2012. Inzet van critical friends bij professionaliseren van leraren. *LOOK, Open Universiteit*, 1–45. Retrieved from http://www.ou.nl/documents/14300/3ec4f9f8-69ea-4e97-ba18-961dfdd11519

[2]   Edith Ackermann. 2001. Piaget's Constructivism , Papert's Constructionism : What's the difference ? *Constr. Uses Perspect. Educ.* (2001), 1–11. DOI:https://doi.org/10.1.1.132.4253

[3]   Chris Anderson. 2013. The Maker Movement: Tangible Goods Emerge From Ones and Zeros. Retrieved from https://www.wired.com/2013/04/makermovement/

[4]   Ronald A. Beghetto en James C. Kaufman. 2014. Classroom contexts for creativity. *High Abil. Stud.* 25, 1 (2014), 53–69. DOI:https://doi.org/10.1080/13598139.2014.905247

[5]   Jerome Bruner. 1966. *Toward a Theory of Instruction*. Harvard University Press. Retrieved from http://users.ugent.be/~mvalcke/WD_1314/bruner_cis.pdf

[6]   Wouter van Casteren, Anja van den Broek, Rob Hölsgens, en Jules Warps. 2014. *Wetenschap en Technologie op de pabo*. Nijmegen.

[7]   Ada van Dalen en Martine van Schaik. 2014. *Excellentiebevordering door middel van onderzoekend en ontwerpend leren*. Retrieved from http://www.schoolaanzet.nl/fileadmin/contentelementen/school_aan_zet/Opbrengsten_CfP_2013-2014/Lessenserie_Vergroot_je_kamer_DEF.pdf

[8]   Robert H. Ennis. 2002. A Super-Streamlined Conception of Critical Thinking Robert. Retrieved from http://faculty.education.

illinois.edu/rhennis/SSConcCTApr3.html

[9]   Jackie Gerstein. 2016. Maker Education: Pedagogy, Andragogy, Heutagogy. Retrieved from https://usergeneratededucation.wordpress.com/2016/06/14/maker-education-pedagogy-andragogy-heutagogy/

[10]   Marja van Graft en Pierre Kemmers. 2007. Onderzoekend en Ontwerpend Leren bij Natuur en Techniek: Basisdocument over de didactiek voor onderzoekend en ontwerpend leren in het primair onderwijs.

[11]   Marja Van Graft, Martin Klein Tank, en Theo Beker. 2016. Wetenschap & technologie in het basis en speciaal onderwijs. Retrieved from http://downloads.slo.nl/Repository/wetenschap-en-technologie-in-het-basis-en-speciaal-onderwijs.pdf

[12]   Erica Rosenfeld Halverson en Kimberly Sheridan. 2014. The Maker Movement in Education. *Harv. Educ. Rev.* 84, 4 (2014), 495–504. DOI:https://doi.org/10.17763/haer.84.4.34j1g68140382063

[13]   Michelle Hlubinka, Dale Dougherty, Parker Thomas, Stephanie Chang, Steve Hoefer, Isaac Alexander, en Devon Mcguire. 2013. *Makerspace Playbook*. Retrieved from http://makered.org/wp-content/uploads/2014/09/Makerspace-Playbook-Feb-2013.pdf

[14]   Jennifer Klepper, Jahnell Pereira, en Zach Zayner. 2017. *Maker Education. Effective Implementation in 21st Century Classrooms*.

[15]   Marijke Kral en Marie-José Kuypers. 2016. Businessplan 2017-2020 iXperium, Centre of Expertise leren met ict, 2.0.

[16]   Douglas Llewellyn. 2002. *Inquire within: Implementing inquiry-based science standards*. Corwin Press.

[17]   Lee Martin. 2015. The Promise of the Maker Movement for Education. *J. Pre-College Eng. Educ. Res.* 5, 1 (2015). DOI:https://doi.org/10.7771/2157-9288.1099

[18]   Arjan van der Meij. 2015. Vier Maker Education Mythes ontkracht. 8. Retrieved from http://makered.nl/vier-maker-education-mythes-ontkracht/

[19]   Seymour Papert. 1980. *Computers and computer cultures*. Retrieved from http://isites.harvard.edu/fs/docs/icb.topic1437166.files/papert1980pp19-37.pdf

[20]   Seymour Papert en Idit Harel. 1991. Situating Constructionism. (1991). Retrieved from http://namodemello.com.br/pdf/tendencias/situatingconstrutivism.pdf

[21]   Platform Onderwijs2032. 2016. *Ons onderwijs2032 Eindadvies*. Platform Onderwijs2032, Den Haag. Retrieved from http://onsonderwijs2032.nl/wp-content/

uploads/2016/01/Ons-Onderwijs2032-Eindadvies-januari-2016.pdf

[22]   Trisha Roffey, Catherine Sverko, en Janelle Therien. 2016. *The Making of a Makerspace: Pedagogical and Physical Transformations of Teaching and Learning*. Retrieved from http://www.makerspaceforeducation.com/uploads/4/1/6/4/41640463/makerspace_for_education_curriculum_guide.pdf

[23]   F Sanchez. 2016. 6 things to consider before starting your makerspace. Retrieved from http://blogs.mtlakes.org/nothingbutnet/2014/10/20/steps-to-designing-maker-spaces/

[24]   SLO. 2015. Poster Onderzoeken en ontwerpen. Retrieved from http://downloads.slo.nl/Documenten/Poster-A3-OenO-v2.pdf

[25]   Rachel Charlotte Smith, Ole Sejer Iversen, en Mikkel Hjorth. 2015. Design thinking for digital fabrication in education. *Int. J. Child-Computer Interact*. 5, (2015), 20–28. DOI:https://doi.org/10.1016/j.ijcci.2015.10.002

[26]   J. Richard Suchman. 1965. Learning through Inquiry. *Child. Educ*. 41, 6 (1965), 289–291. DOI:https://doi.org/10.1080/00094056.1965.10728968

[27]   Techniekpact. 2013. *Nationaal Techniekpact 2020*. Retrieved from http://techniekpact.nl/cdi/files/f1441a07a7dab41382fd20095b-16c618ad14773c.pdf

[28]   Annette Thijs, Petra Fisser, en Monique van der Hoeven. 2014. *Digitale geletterdheid en 21e eeuwse vaardigheden in het funderend onderwijs: een conceptueel kader*. Enschede, the Netherlands. Retrieved from http://www.slo.nl/downloads/documenten/digitale-geletterdheid-en-21e-eeuwse-vaardigheden.pdf/

[29]   Mirjam van Tilburg. 2016. Grip op maakonderwijs. Retrieved from http://www.lkca.nl/~/media/downloads/bijeenkomsten/onderzoeksconferentie/2016/grip-op-maakonderwijs.pdf

[30]   Peter Troxler. 2016. *Niet alleen "omdat het kan"*. Amsterdam. Retrieved from https://waag.org/sites/waag/files/public/media/publicaties/pme-onderzoek-kennis-maker-education.pdf

[31]   Joke Voogt en Natalie Pareja Roblin. 2010. *21st Century Skill, Discussion Paper*. Retrieved from http://portal.ou.nl/documents/23372050/23372156/voogt_pareja+roblin_2010_21_st_century_skills__discussie_paperNL__def.pdf

[32]   Tim van Wessel, Maarten Kleinhans, Hanno van Keulen, en Anne Baars. 2014. Wetenschapper in de klas.

[33]   Symen van der Zee. 2017. Op weg naar de onderzoekende pabo. Wetenschap & technologie verduurzamen op de pabo. 28. Retrieved from http://www.fi.uu.nl/publicaties/literatuur/2017_zee_whitepaper_onderzoekende_pabos.pdf

Adapting Maker Education to pupil's abilities: How clear bordered tasks can lead to discovery behaviour

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ABSTRACT

Maker education uses the concept of learning through interaction of the hand and the mind and is therefore a good instrument for Design and Technology education. However it appears to be difficult to engage all pupils in a class. Still, it is in all pupils' interest that all pupils are enabled to engage, because only then a strong community of makers can emerge.

Engagement can be hindered by the absence of abilities, needed to accomplish a task. When this leads to passiveness or frustration, it may disturb the group process of collaboration.

In earlier research we found out that adjusting simple challenges to pupils' abilities and adding clear success criteria to create a manageable 'cognitive conflict' is a way to border a task. Within these borders there is room for freedom. This freedom can result in ongoing discovery behaviour. A joint evaluation of the various results of the task will lead to joint development of knowledge, leading to a next level of familiarity. This joint knowledge together with the by discovery behaviour expanded abilities, outlines the base of a next task.

When for some pupils the devised borders fail, diagnosis of the failing border will be simple; is it a failing adjustment to pupil's abilities, or is it a too complex challenge, or is it a vague success criterium or is it a failing joint evaluation? After diagnosis offering proper support is easy.

In this study we researched the actual effect of a series of clear bordered tasks on the discovery behaviour of the pupils. In the tradition of lesson-study [11] we focused on if and how this approach was useful to get disruptive pupils active in discovery through making.

The results showed that the tasks turned out to be useful in changing the observed pupils' behaviour towards active making and discovery. As a result of the improved discovery behaviour the teacher-pupil relationships and the pupil-pupil relationships improved as well.

KEYWORDS

Attitude, task structure, ability, inability, collaboration

1 INTRODUCTION

Maker education is recognised as a good instrument for Design and Technology education, because it uses the concept of learning through the interaction of the hand and the mind [1]. The importance of knowledge gained by experience as an anchor for abstract thinking is recently confirmed by Hayes & Kraemer [2]. Sennett [3] arguments that doing a job properly takes the time it takes. While we are making, submerged processes of thought and feeling are in progress. Making also suits pupil's natural learning process through hypothesis testing [4]. When a pupil finds out that a self thought out solution turns out to be not working, this perception subsequently naturally leads to seeking to improve.

What are the competences conveyed by maker education, and how are those competences acquired? Especially in the context of a school class is this an issue of interest. Sennett [3] points out the significance of specific abilities within a task. To start discovery behaviour competence in several skills is needed. Not only practical skills, but also skills, utilised in virtually every aspect of our lives - how we work, do, play, socialize and learn, are required. Which abilities are needed to evoke active discovery behaviour during the performance of a task and which inabilities prevent pupils from active discovery behaviour? Such inabilities can be seen as calls for avoidance or support. Awareness of pupil's needs during maker education can help a teacher to create doable tasks.

However, the importance of such awareness of needs is generally hardly recognised. As a result, frustration for a minor percentage of the pupils is just around the corner. Unfamiliarity with specific competences, needed to accomplish the task, can lead to frustration and passiveness. It is precisely these frustrated pupils, who should require maker education to get rid of frustration resulting from inability. If their frustration is not solved, they can later on disturb the group process of collaboration. It is in all pupils' interest that all pupils are enabled to join maker education lessons. This enables the emergence of a strong community of makers, comprising the whole class of pupils. In a strong group, pupils are in a positive way aware of both their weaknesses and their strengths. They can variable take the expert or the novice role, depending on their skill level in a situation, important issues during collaboration.

1.1 Theoretical framework

The importance of awareness of abilities and inabities for the creation of an effective educational task is in line with the ideas of Vygotsky [5], who argues that the function of an educational task is to create a bounded "cognitive conflict" in the pupils (Table 1, Nr. a) and is in the zone of proximal development. A bounded cognitive conflict initiates reconsideration of ideas (Table 1, Nr. b, leading to discovery behaviour and finally to knowledge development.

A task with an unbounded cognitive conflict, will be perceived as a concern and can result in passiveness or frustration; the task is in the zone of ontological discomfort (Table 1, Nr. c). According to Dewey [6], such a task is useless with regard to discovery behaviour and knowledge development (Table 1, Nr. d).

The absence of a cognitive conflict is also not helpful for discovery behaviour. A task in the zone of actual development is perceived as not challenging and cannot hold pupil's attention (Table 1, Nr. e), because there are no ideas to be reconsidered. Such a task can eventually function as a test or check of the actual development, but will not lead to new knowledge development.

Table 1: Relation between behaviour and task

Nr	pupil's be-haviour	task characteristic
a	attentive	fascinating subject
b	active	challenging
c	unwilling	frustrating
d	passive	unfamiliar
e	bored	not challenging
f	ongoing active	clear and familiar expectations
g	undirected active	absent directing expectations
h	decreased active	absent directing expectations

For this reason we developed in a former research paper, through a series of case-studies [7] a task structure ensuring a bounded cognitive conflict showing in discovery behaviour (Fig. 2).

Such a task is based on:

- Clarity of the situation for the whole class, because of familiarity of the context and of all the required skills

- Simplicity of the challenge

And defined by (Table 1, Nr. f):

- Simplicity of the criteria for a successful performance of the task (absence leads to Table 1, Nr. g)

- Clarity of the results for the whole class through joint evaluation (absence leads to Table 1, Nr. h)
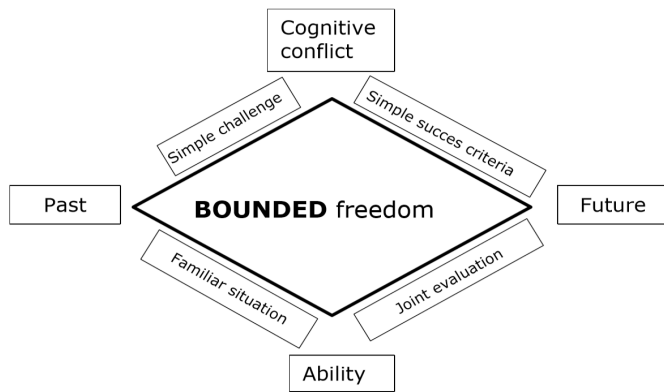
Figure 2: Task-structure supporting discovery behaviour

This model on task structure can help to adapt the task at hand to the pupils.

This model can be used in the tradition of Science, Technology and Mathematics education leading to a structured acquisition of skills. An example of this tradition is STEAM education. This educational approach to learning uses Science, Technology, Engineering, the Arts, and Mathematics as access points for guiding student inquiry, dialogue, and critical thinking. The end results are students who can take thoughtful risks, engage in experiential learning, persist in problem-solving, embrace collaboration, and work through the creative process [8]. When a thoughtful program of STEAM assignments is planned, teachers can be ensured of the familiarity of a wide range of skills amongst their pupils.

The model (Fig. 2) can be helpful to create tasks, enabling pupils to build on existing knowledge and experience [9]. Through adaptation of the learning situation it is possible to build on pupil's experiences as well as to promote positive skills and dispositions [10].

When pupils fail to show discovery behaviour, adapting the task to the pupils by means of clear borders as shown in the model (Fig. 2) can help to create room for freedom in order to start ongoing discovery behaviour.

2 CASE STUDY

In this paper, we focus during Design and Make Education in a microscopic way on the connection between pupil's discovery behaviour and a succession of to the pupils adapted bordered tasks. Do right adapted clear bordered tasks help to initiate discovery behaviour? We investigated through observation and action research the behaviour of about forty-nine to twelve years olds on a Montessori school. The reason for this study was the fact that the researcher noticed specific problematic behaviour during a former experience - while working as an out-of-school-care teacher- with some pupils on this school. A small, but dominant group of children then regularly showed rebellious and defensive behaviour. Six months later, these same children continued to disrupt lessons, in particular the Arts and Crafts lessons. The management was looking for the origin of the failing Arts and Crafts lessons. The researcher just completed a three months pilot study of about sixty six- to nine-years-olds, together with another Arts and Crafts teacher. The study was on the relationship of task elements and discovery behaviour and had resulted in increased discovery behaviour for all pupils. Because of that result the management asked the researcher to study the origin of the failing lessons in the older group of pupils.

The researcher started the study with an orientation period, in which the researcher assisted the Arts and Crafts teacher in order to get acquainted with her approach. Additionally, the researcher informed herself about other possible origins of the disrupting behaviour during Arts and Crafts, for instance raised by class supervisors or daily class practice. During these lessons the researcher noticed the problematic behaviour all the time. By behaving like this tis small group of pupils serious disturbed the lessons. The question from the class supervisors was "Is it the teacher, who triggers this behaviour?" Because of the experienced improvement of behaviour during the first pilot study in the six to nine years olds classes, the researcher changed the research question in "Is it the lesson, that triggers this behaviour?".

To answer this question the Arts-and-Crafts teacher and the researcher together started a case-study, whereby the researcher assisted the Arts-and-Crafts teacher during class and coached her on the fly to notice the relationship between task elements and the appearance/disappearance of discovery behaviour. During the first pilot study one important characteristic of the challenge in a task emerged; simplicity. Other characteristics appeared to be ability (as a result of familiarity) and simple success criteria. Through joint evaluation of all the results of the task, clarity and familiarity for the whole class was acquired (fig. 2).

The teacher and the researcher planned a series of bordered tasks and put these central during the lesson-sessions, one at the time. In the tradition of lesson-study [11] the researcher especially wanted to know if this approach to the tasks could help the pupils, who were known for their rebellious and defensive behaviour in Arts-and-Craft classes, to overcome frustration and to realise ongoing discovery behaviour.

Therefore, the central research question of this case study was: "Does the transformation of a design and making assignment into a collection of clear bordered tasks affect pupil's discovery behaviour?"

2.1 Methodology

The researcher observed pupil's behaviour on three days, during assisting the lessons. She also video recorded all sessions from a fixed place, with

Nr	Task	Joint evaluation [10]
1	draw a chair on a piece of paper	sharing and evaluating all models
2	draw the components of the chair on paper	
3	cut out the components with scissors	
4	assemble the components with glue	sharing and evaluating all models
5	If necessary; re-design	
6	draw the components on cardboard e	
7	cut out the components with a knife	sharing and evaluating individual progress
8	assemble the components with glue	sharing and evaluating individual progress
9	If necessary; solve construction problems	
10	colour and finish your chair	sharing and evaluating all models

Table 2: Tasks succession in case-study "Make a mini-chair"

the objective to have an extra, impartial eye to review the sessions. At the fourth day of the sessions the researcher was absent, but the teacher reported her after the lesson by phone. The series of lessons were given three times a day, to a group of eight to thirteen pupils aged nine to twelve years old. At the school were two school classes for the nine- to twelve-year-olds. The composition of the groups was done by the two class supervisors. Each group comprised pupils of the two school classes.

Each day and on the fly the researcher shared what she witnessed with the teacher. She shared witnessed behaviour of the pupils and of the teacher in relation to task characteristics, in order to feed her awareness of the relationship.
The STEAM assignment "Make a mini chair" [12] suited the succession of simple tasks. The tasks were adjusted (Table 2) to the model (fig. 2). The proceedings during the appliance of this assignment are described for all three groups in the next paragraphs.

2.2 Sessions

2.2.1 The first session.

After a PowerPoint introduction about the function of a chair and the purpose of the assignment, in short, all tasks were identified. All pupils started with the first task, drawing a chair on a piece of paper. When finished, they could start with the second task, drawing the components of the chair on paper. After, they were allowed to continue with cutting out the components with scissors and then to assemble the components with glue (Fig. 3). Dependent on pupil's contentment with their paper model, they could re-design or start to draw the components on cardboard. At the end of the first session the pupils were working on various stadia of the assignment, depending on their progress. Where a single pupil was already getting around with cutting the cardboard components, was one third of the pupils still in the "draw components

on paper" phase. A few pupils did not get past the "draw a chair on paper" phase. At the end of the first session it was intended to share all chair models and evaluate the process of transforming the 2D model into 3D parts, but the teacher and the researcher forgot to do this in all three groups.

Figure 3: First session. Working with paper

2.2.2 The second session.

In the first group it showed that a rather large number of the pupils did not manage to transform the 2D model into 3D parts. After evaluating this process, all pupils managed to make a 3D paper model of a chair and most of them managed to start cut out the components with a knife. Therefore, we started in the other two groups with evaluating the transformation of 2D into 3D. In all groups some pupils already managed to assemble the components with glue. A short sharing of products and applied procedures ended this session. The focus of attention during the main part of this session was –besides the transformation from 2D to 3D- on the handling of the knife.

2.2.3 The third session.

During the third session all pupils were working hard on cutting and assembling. A significant number of pupils could already colour and finish the chair (Fig. 1). During solving construction problems some children got brilliant and simple ideas about a new model or about fixing stability problems (Fig. 4).

Figure 4: Third session. Working with card board

2.2.4 The fourth session.

During the fourth session, most pupils finished their chair. The teacher made a small exposition in the central hall. The teacher told the researcher, that the atmosphere was really good; pupils enjoyed the working. One third of the pupils finished the assignment during the fourth session and worked on a self-chosen job.

2.3 Discovery behaviour of the pupils

During the first session, many pupils were distracted by the video camera. After explaining the function of the camera (an extra, independent watching eye) most pupils stopped paying that much attention to the camera. However, some children were so much distracted by the camera, that they could not control themselves enough to concentrate on the assignment. They liked watching themselves on camera more than working on the assignment. In the third group (14 pupils) it was not so much the camera, that disturbed the lesson. The bad mood for arts-and-crafts lessons of six dominant boys disturbed the lesson and the atmosphere. In this group not much work was accomplished; neither by the uncooperative pupils, nor by the cooperative pupils.

The second session was planned to be about cutting. The teacher instructed the drawing of chair parts on the cardboard and the handling of the knife during cutting out the parts. During this session, the researcher diagnosed in the first group an inability of a major part of the pupils to think in 3D about their 2D chair creation. As a result, the pupils got stuck and the general behaviour was unfocused. The researcher suggested the teacher to pause the lesson for a short explanation and later on the researcher scaffolded the transformation from 2D to 3D for some pupils. More support was not required, because the pupils looked at each other and helped each other.

In the second and third group the teacher started with asking attention for 3D thinking followed by instruction about holding the knife during cutting.

The second group was directly working enthusiastic and focused.

In the third group only four of the six pupils, who showed disturbing behaviour during the first session, still showed disturbing behaviour. The researcher suggested the teacher to instruct and guide the willing pupils. At the same time the researcher discussed the why of their rebellious and defensive behaviour with the unwilling boys and offered them help for whatever which problem they would meet. This resulted in motivated working by two boys. The other two boys were still defensive, but started, while guided through a step by step demonstration, scaffolded working. The two boys' 3D drawing followed by the construction of a paper chair was going well. New problems showed up during cutting the cardboard. They appeared to be clumsy regarding handling the knife, but this time they were open for help and they started trial and were active in making.

Interpreting the second session we can say, that during session two, attentive ongoing discovery behaviour was achieved for all pupils in all three groups. The former disruptive pupils were still a bit defensive, but they gradually relaxed more and more.

At the end of the session, during joint evaluation, every pupil showed his/her work and reported shortly about the process followed and plans for the next session.

The third session was intended to be about constructing and finishing, but a lot of pupils were still busy with cutting. The teacher instructed the construction of the cardboard chairs and the use of the special glue. A specimen of a chair, made by the researcher was showed to illustrate some possibilities for solving construction problems, like instability.

The groups were differently composed this time, because of testing in the classes. The moment a pupil could go to Arts-and-Crafts depended on the moment of testing in class.

The first thing the researcher noticed in all groups was the joy the pupils showed during making. There was certainly no unfocused behaviour. There was a delivery of varied chairs at a fast pace.

Pupil's behaviour was easy to handle this time for the arts-and-crafts teacher and the researcher. The six during the first session disruptive behaviour

showing pupils were present in an unobtrusive, somewhat clumsy way. Some of the pupils, who in the second session showed inability to think in 3D about their 2D creation appeared to have changed their chair design dramatically. This time, they were actually the ones with big plans to make the same chair at home.

The fourth session was added to allow all pupils to finish their chair. The arts-and-crafts teacher reported that the pupils were easy to handle and proud of their product.

2.4 Analysis

Borders have a limiting function. In the case of a task, borders limit the amount of possible needs of the pupils by eliminating foreseeable inabilities. They also limit the amount of possible needs of the pupils by focusing on only one challenge, in this case the practice of one technical skill. The third border offers a clear and simple expectation about the outcome of the practice; an intermediate product that has to lead to a well-defined end-product. In this case the end-product was a nice, solid and comfortable chair. The last border is created at the end of the task, by joint evaluation, and forms also the first border of the next task. In this case, these borders delivered us transparency, resulting in readily understood needs of the pupils (not foreseen inabilities and an unexpected low level of the technical skill). These readily understood needs made it possible to offer suitable help to compensate pupils for technical and other inabilities. In this way all pupils were enabled to perform the tasks. Experiencing ability during performance resulted in further development towards ongoing discovery behaviour.

The borders also make it possible for the teacher to offer pupils freedom. The borders will provide for bounded freedom. Together with transparency of needs, as another consequence of borders, the manageability of the lesson will be preserved.

This specific assignment comprised a succession of clear bordered tasks. The borders were as follows: Because every pupil knows that a chair has to serve sitting, the situation seemed to be familiar and the success criteria seemed to be clear and simple. The challenge of each task was found in the application of technical skills. The challenges were simple, because each task was focusing on only one technical skill. The bounded freedom was in the possible variety of chairs from which the pupils could choose. They could choose to make a chair for resting, reading, studying, working at a computer or watching a movie. Every activity has his own demands with respect to the position of the sitting and with respect to solidity. This bounded freedom enriched the joint evaluations. Through these rich joint evaluations every pupil gained more knowledge than they would have gained in the case of absent freedom of choice.

This was also true for the pupils with signaled rebellious and defensive behaviour. It mitigated after the researcher and the teacher, during dialogue, had showed recognition and had offered appropriate support. Apparently, this dialogue restored these pupils' secure feelings.

At the end of the first session, immediate recognition of needs was hindered, because the evaluation-phase was omitted. The significance of the forgotten evaluation showed up in de second session. In the first group a rather large number of the pupils did not manage to transform the 2D model into 3D parts. This lastly made the teacher and the researcher together reflect on the first session. Through this reflection they became aware of earlier not recognised needs of the pupils. After the insertion of a joint evaluation of the transformation of the 2D thinking into the 3D thinking in the first part of the second session, pupil's needs decreased, which enabled the teacher and the researcher to adequate support the remaining needs. After this support, the pupils further on looked at each other and helped each other. Subsequently all pupils managed to make a 3D paper model of a chair and most of them managed to start to cut out the components with a knife. This inserted joint evaluation resulted in improved discovery behaviour in all groups.

3 CONCLUSIONS AND DISCUSSION

3.1 Conclusions

In summary; the pupils made nice and diverse chairs (Fig. 1). In the process they discovered much about chair construction. By using the model (fig. 2) for the creation of the tasks within the assignment, the pupils met many simple challenges, which triggered them to a lot of design and redesign, making, and problem-solving activity.

Through joint formative evaluation at the end of each session the pupils discovered impossibilities. Some of these discoveries resulted in a need for redesign. For instance, the discovery that the cardboard was not the right material to make a favourite chair of.

Joint formative evaluation took place at the end of task 1, 4, 7, 8 and 10. At the end of task 1 the pupils encountered eventual problems with the conversion from 2D to 3D. At the end of task 4, they encountered eventual construction problems with respect to solidity. At the end of task 7 and 8 they were confronted with construction problems regarding stability and at the end of task 10 they could reflect on the relationship between appearance of the chair and the design features.

The simplicity of the encountered problems created clear and solvable challenges. For instance, the transformation from a 2D chair to a 3D chair, the handling of the knife, problem solving in the construction-phase. This resulted in active ongoing

behaviour even when problems had to be solved. Therefore, the beauty of the assignment was the logic of the successive simple tasks.

It was nice to see that all pupils' behaviour by offering adequate support was improving over time. At the start a small, but dominant percentage of the pupils was behaving rebellious and defensive. Mid-term their behaviour was changed into asking for help and trial.

Insufficient scope for pupils to follow their own interests and using their strengths is often mentioned as a disadvantage of closed assignments. This was not the case for this closed assignment, composed of clear bordered tasks. The clear bordered tasks offered the pupils a lot of bounded freedom and in addition a chance to collaborate and cooperate.

Of course, could a succession of clear bordered tasks also take place in the case of an open assignment, but the additional benefit of natural collaboration and cooperation as a result of generally experiencing the same possibilities and impossibilities will be absent. By this absence, the practice of several much-needed skills, utilised in collaboration and cooperation, such as awareness of other pupil's needs, dialogue, practical assisting, problem solving, explaining will reduce. Furthermore, joint evaluation is impossible, because each pupil is making something different. Therefore, it is more difficult to make discovery behaviour flourish for all pupils during open assignments, because they miss -besides a structured accomplishment of knowledge through joint evaluation- knowledge development through learning from each other and through helping each other.

3.2 Limitations

This case-study covers the proceedings of a Design and Technology assignment in a Montessori school class, guided by an Arts-and-Crafts teacher together with the researcher as assistant. The abilities and inabilities of the pupils in this context can be different from the abilities and inabilities in regular school classes, because pupils in a Montessori tradition are considered to be enabled to operate autonomously.

3.3 Implications

The results implicate that a stepwise assignment, composed from clear bordered tasks suits discovery behaviour during Design and Maker education in school classes. This task structure is not only provokes ongoing discovery behaviour, but it also enables teachers to become aware of pupil's abilities and inabilities. This knowledge can be used by teachers to build next tasks and challenges on [13]. Awareness among pupils of each other's abilities and inabilities allows cooperative behaviour and collaboration.

Teachers working in traditional education often mention passive or passive aggressive behaviour as problematic behaviour. An explanation for that can be that, when pupils are used to teachers taking the lead, they are not used to operating autonomously. In case of inability they seize activity.

By contrast teachers working in a Montessori tradition more often mention defensive or rebellious behaviour as problematic behaviour. An explanation of that can be that autonomous behaviour and inability are incompatible. An autonomous answer to inability is avoiding the inability and choosing for another, mastered activity. This will lead to rebellion when the teacher disputes their choice.

Now, we have found the described results on pupil's behaviour in a Montessori tradition, it would be interesting to research the effects of a succession of simple tasks on pupil's behaviour in a traditional school. What are the similarities and what are the differences with our findings?

Another interesting item for further research would be reproducibility. Although we looked in a pre-trial into the practice of another teacher with a different age-group, this study only deals with one researcher, one school, one Arts and Crafts teacher and one age-group of pupils. Other researchers and other teachers can help to fine-tune the characteristics of a clear bordered task. They also can help to find alternative ways of supporting and of applying bordered tasks.

Furthermore, it would be most interesting to search for new ways to facilitate teachers to enable practical self-discovery of the virtues of clear bordered tasks in relation to the abilities and inabilities of their pupils. By practical discovery teachers could learn to apply the model and start to see possibilities to handle pupil's abilities and inabilities themselves and become enabled to create clear bordered tasks themselves.

4 FINAL REMARKS

We can conclude that the closed, stepwise assignment, through the manageable acquisition of skills, benefitted cooperative and collaborative behaviour. For instance, during the second session, after a short scaffolding of 2D to 3D thinking, the pupils further on looked at each other and helped each other. The simplicity of the encountered problems created clear and solvable challenges, leading to a lot of active design and redesign. Through cooperation and collaboration pupils helped each other and learned from each other [14].

After the development of cooperative and collaborative skills during closed assignments, cooperation and collaboration between pupils and pupils and teacher can also make the successful proceeding of open assignments feasible. Thus, a closed assignment can pave the path for an open assignment.

In turn an open assignment can function as an opportunity to exercise certain skills. Then, the assignment is free, but the method is prescribed.

REFERENCES

[1] Papert, S., Harel, I. (1991). Situating Constructionism. Constructionism 36, 1-11. New York, NY: Ablex Publishing Corporation

[2] Hayes, J.C., Kraemer, D.J.M. (2017). Grounded understanding of abstract concepts: The case of STEM learning. Cognitive Research: Principles and Implications, 2(7). doi 10.1186/s41235-016-0046-z.

[3] Sennett, R. (2009). The craftsman. London, England: Penguin Random House.

[4] Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research and policy implications. Science 337(6102), 1623-1627 doi: 10.1126/science 12223416.

[5] Vygotsky, L.S. (1978). Mind in society. Cambridge, MA: Harvard University Press.

[6] Dewey, J (1910). How We Think. Mineola, NY: D.C. Heath & Co, Publishers

[7] Looijenga, A., Klapwijk, R.M., de Vries, M.J. (2018). Attention and action during the Design and Technology lesson: by fine-tuning task characteristics. In Seery, N., Buckley, J., Canty, D., Phelan, J. (Eds.), 36th International Pupils' Attitudes Towards Technology Conference. Research and Practice in Technology Education: Perspectives on Human Capacity and Development (pp. 278-287). Athlone, Ireland: Technology Education Research Group.

[8] EducationCloset. (2014-2016) The STEAM Portal by EducationCloset. Retrieved 2018, June 4, from https://educationcloset.com/steam/what-is-steam/

[9] Dewey, J. (1938). Experience and Education. New York, NY: Kappa Delta Pi

[10] Creative Little Scientists (2014). Recommendations to Policy Makers and Stakeholders. ISBN: 978-960-473-516-7. Retrieved from: http://www.creative-little-scientists.eu/

[11] Hiebert, J., & Stigler, J.W. (Sep., 2000). A proposal for improving classroom teaching: Lessons from the TIMSS Video Study. The Elementary School Journal, 101(1), 3-20.

[12] Petiet, R. (2009). Techniek - krachten Retrieved 2018, February 10, from http://montessorinet.ning.com/forum/topics/techniek-krachten/

[13] Mercer, N. (2013). The social brain, language, and goal-directed collective thinking: A social conception of cognition and its implications for understanding how we think, teach, and learn. Educational Psychologist, 48(3), 148-168. doi: 10.1080/00461520.2013.804394

[14] Black, P., Wiliam, D. (2009). Developing the theory of formative assessment. Educational Assessment, Evaluation and Accountability 21(1), 5-31. DOI: 10.1007/s11092-008-9068-5

Where MakerEd meets Change-MakerEd
The journey to the Classroom

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ABSTRACT

For more than twenty years the Maker Movement has been gaining momentum and more recently is gaining a foothold in education. In this paper we will describe the designathon method which combines elements of Maker Education with the structure and empathetic approach of Design Thinking in order to allow children to prototype solutions for global issues, such as the Sustainable Development Goals (SDGs)[1]. We will endeavour to describe and discuss the connections between Maker Education, Design Thinking in an educational context and Change-maker education (a very new field) and how elements of these approaches combined can contribute to the agency of today's children and tomorrow's engaged citizens.

In fact, empowering children to be creative while spreading awareness about the importance of engaging children as co-creators of society is rapidly becoming a key objective of education today, see the "The Future of Education and Skills : Education 2030" [2]. Then, through several case studies from around the world, we will show examples of ideas and attitudes discovered during the application of the designathon method in both in-school and extra-curricular contexts. We will present evidence that both teachers and pupils are enthusiastic about the (learning) outcomes and engagement of children when tackling global issues. We will however make the argument that adults often have the misconception that children are uninterested in and incapable of thinking about complex world problems, while quite the opposite is the case. Presumably this misconception hinders further uptake. Lastly we will argue that, by tackling global environmental and humanitarian issues, which are regularly touched upon content wise in primary school curricula globally, one opens the possibility to bring empathetic and constructionist learning into the classroom.

KEYWORDS

Maker Education; Design Thinking; Change-maker; designathon; SDGs; agency; Future ready.

Maker Movement and Maker Education

While an exact definition of maker education is not universally agreed upon, we learn from Gary Stager and Sylvia Martinez that the Maker Movement is "a technological and creative revolution around the world". [3]. Fortunately for educators, the Maker Movement 'overlaps with the natural inclinations of children and the power of learning by doing'[3]. Combining elements of Constructivism[4] and Constructionism [5], Maker Education strives for the development of the individual through physical and social interaction with the world, often within the context of fabrication. "Furthermore, the Maker Movement sees tools and technology as the essential elements for solving complex problems. New tools and technology, such as 3D printing, robotics, microprocessors, wearable computing, e-textiles, "smart" materials, and new programming languages are widely available, facilitating the growth of a vibrant, collaborative community of global problem-solvers.

Design Thinking and the Designathon method

What might the implications be if we could connect these very powerful tools of the Maker Movement for solving problems with an ability to tackle global issues such as the SDG's [1] as an educational experience for children? For as The Maker Movement sees technology as essential to solving problems;

Design Thinking incorporates empathy, a human centred approach and creative thinking. Does this combination offer us possibilities to bridge "making" with curriculum contents? Can children learn, through grappling with global issues the competencies to design a better world for themselves and the planet? Armed with these urgent and relevant questions and her experience across 22 countries over 12 years as a co-founder of Butterfly Works as head of the Global Learning team, she began to craft workshops for children between the ages of four and twelve which are designed for this purpose. Through one year of hand's on prototyping and testing, regarding theme's type. duration, ways of scaffolding, materials and tools we have settled on a repeatable and shareable method called the 'designathon'

A designathon is a structured workshop in which children (ages 4 - 12 years) invent, build and present their self-devised (technological) solutions to a social or environmental issue around the Sustainable Development Goals. A workshop lasts two to six hours, depending on the age group and is facilitated by education professionals. The word `designathon' is inspired by the words marathon and hackathon. A designathon always has a set issue, which is introduced through dialogue, helped by slides and videos to inform the children about the variety and diversity of problems and to inspire them with existing creative (technological and otherwise) solutions. Examples of issues are waste, mobility, water and children's rights. An essential part of the method is that the children, in groups, define the aspect of that issue they wish to work on, ensuring their connection and motivation. All designathon projects follow the same design cycle (Figure 1.) A description of all learning goals of a designathon can be found in this position paper [6]. The process is scaffolded though tools. In the ideation step for example children use an 'Ideation worksheet', to assist their group through the divergent and convergent creative process while the 'Make' step has a specific Maker Kit containing enough electronic components for 30 children to create semi-working prototypes, including, motors, led lights, switches, ventilators, alarms and wheels amongst others.

Examples of concepts which have emerged in a Designathon workshop and show children's ability to combine the technological with the societal include:

- a 3D food printer to tackle hunger amongst homeless people
- a prototype for an electric bicycle for a friend with a physical handicap

- a self-driving google car that cleans the streets which you can text to come and clean your own street.

Figure 1: The Designathon method design cycle.

Working with this combination of Makers Education and Design Thinking has two possibly interesting effects. The first has is primarily concerned with the growth of the individual. According to Carlson, S. M., White, R. E., & Davis-Unger, A. C. [7] 'practice in pretending' helps individuals conceptualise alternative ways of being and results in more creativity and better problem-solving. Also, an important benefit of early pretend play is its enhancement of the child's capacity for cognitive flexibility and, ultimately, creativity [8]. Practice in thinking about and creating solutions for complex real-world problems can result in improved problem-solving and creativity. The second effect, which is more closely related to this paper, is concerned with the way the individual sees him/herself as a part of the greater whole of society. In the next section we will discuss the importance of agency and the ability to see oneself as a Change-maker.

Change-maker Ed

A change-maker, according to Ashoka [9] who first popularised the term, is any child or adult who is taking creative action to solve a social problem. Beyond this taking of creative action, a change-maker is an individual who is intentional about solving a social problem for the greater good; is motivated to act and is creative in their approach. Ashoka's vision for an "Everyone a Change-maker" world is rooted in an urgency for a better way to solve social problems, especially given the increasing rate of change in the world. The democratisation of the term allows for the empowerment of all individuals purposefully working for positive change in their communities. Good to note that our working definition of the change-maker role is not limited to someone who dedicates their life to leading world

changing projects but also encompasses those, young and old who, with intention, make small and local contributions.

Paulo Freire, founder of "critical pedagogy", was an advocate for education as a form of empowerment and argued that learners should go from the "consciousness of the real" to the "consciousness of the possible" as they perceive the "viable new alternatives" beyond "limiting-situations" [10]. Therefore, students' projects should be deeply connected with meaningful problems, either at a personal or community level, and designing solutions to those problems would become both educational and empowering (Blikstein, 2013) [11].

In the next section we will describe various case studies of Designathon. We will discuss the discrepancies in the expectations of adults towards the abilities of the children and the actual results. We will show instances where the children reflect metacognitively on their own agency. We shall show examples where children have found solutions so viable that cities are considering their implementation and we will discuss the differences and similarities of the attitude and work of the children and teachers from different communities around the world. Afterward we will discuss the challenges of the incorporation of this sort of education into regular school practice.

CASE STUDIES

Case Study 1: The Global Children's Designathon

The Global Children's Designathon is a yearly event, held in 2017 for the 3rd time, and is a day dedicated to what the world could be like when children design better futures using new technologies. On November the 11th 2017, 600 children from 18 cities [12] around the world, worked in parallel to design and develop solutions and innovative concepts for global water issues; building prototypes and sharing ideas with each other via a live connection. At the end of the day the children presented their work to a live audience and a panel of experts. The outcomes of the day were collated in a report called Global Voices of the Next Generation: Water [13] which was presented to the WEF Future Council in Dubai. This research has been dealt with more extensively in the paper "Cultivating children's potential as change-makers: Notes on rethinking how society sees children's role in shaping the future" [14].

Research was conducted on November the 11th 2017 during the Global Children's Designathon in nine of the participating cities: Montreal, Amster-

dam, Singapore, Tunis, Zagreb, Milan, Dar es Salaam, Dubai and Goa. The research took place simultaneously and was orchestrated remotely from Amsterdam's Designathon Works headquarters. During and after the program, the children were asked to fill in a questionnaire regarding all aspects of the work they had just done. Adults who were co-facilitating the events also filled in a questionnaire, responding to questions about their own expectations and observations of the creativity and engagement of the participating children.

The results of this study have been grouped into the following thematic groups:

1: Children's self-awareness and thoughts on their role as decision makers

2. Adult's feedback after being given the opportunity to see children's collaborative and creative skills in tackling global issues:

When asked if children should rule the world, most thought it best if children and adults work together, 45% said yes and 55% said no. They nearly all however nuanced their answer with a suggestion for collaboration between children and adults with their different capacities.

"Kids have great ideas but they need adult guidance to implement them." Shona, 9 years

The children who participated appeared very aware of their lack of experience in the world and the role that adults play in supporting them. Perhaps more surprising are the reactions of the adults to the children. Here are a few examples of the adult's feedback after being given the opportunity to see children's collaborative and creative skills in tackling global issues:

I was surprised by how quickly and efficiently some of the children worked"
Iris, Montreal's Ethnographer

"What surprised me the most was to see how children are able to think and ideate complex systems: Their inventions are not only objects per se, but instead interactions among people, animals, plants and other objects that connect systematically with each other."
Elena, Design Researcher / Facilitator, Milan

Case study 2: Singaporean Designathon Training

We held a Designathon training prior to the Global Children's Designathon at the Singapore Science Centre in 2017. Over two days ten educators were trained in the Designathon method including running a Designathon with a group of sixteen local

children. The educators were all active facilitators at the Science Centre running workshops and tours for visiting school classes, two were from the secondary school department, four were from the primary school department and four were from the Tinkering Studio at the Science Centre which is focused on Maker education. On the first day of the training we also had two representatives from the Ministry of Education participating.

On the first day of the training, which includes the theory behind the methodology and a hands-on experience of doing the Designathon process yourself, the facilitators expressed concern that the children in Singapore would not be aware of water problems and would find it hard to identify a prob-

lem to work on. They were also concerned that the children would not be as creative as children in other parts of the world, due to their rigorous and fact-based schooling, the facilitators feared that children would have lost their creative abilities. Singapore's schools have long held a reputation for

Figure 2: Two girls showing their prototype in development to tackle how fish can navigate dams

didactic teaching, rote learning and academic brilliance. Their pupils lead the rankings in the OECD's Programme for International Student Assessment (PISA), a triennial test of 15-year-olds around the world.

When reflecting on the Designathon workshop we had done with the children, at the end of the second day however, a number of the facilitators expressed their surprise that the children had actually been well able to identify water problems in Singa-

pore and globally and that their ideas and proto-types were very creative and quite wonderful in the eyes of the facilitators.

"The children's ideas floored me, I thought they were on a par with adults!"
- Chew Ling Ling, Tinkering Studio, Science Centre Singapore.

"I was surprised that they could empathise with people who have water shortages"
TOH Kang Hui, Science Centre Singapore.

Figure 3: TOH Kang Hui, discussing with children, Science Centre Singapore

Case Study 3: Designathon School Challenge - Afvalscheiden (Waste Separation), Amsterdam

This project was a collaboration between Design-athon Works, the Municipality of Amsterdam and the participating schools. On March 1st, 2017, eight schools sent teams to participate in the one-day Designathon Challenge to design and proto-type a way to separate and recycle waste in their own schools. The prizes included money to make a working version of the winning design. Two of the schools were secondary schools and six were primary schools, all from the Amsterdam area. The criteria for the winners were, a prototype that: had a way to separate the four types of school waste in a user-friendly way; was original; and included a convincing approach to motivating teachers and students to separate waste at school.

We conducted research during the event through questionnaires and interviews which were designed and administered by Monique Pijls of the HvA.
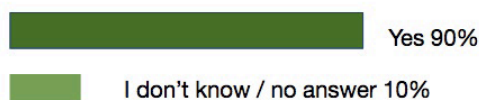

Figure 4: Answers of the 37 children to the question: 'What did you learn today?'

Of the 37 participating children, 90% indicated that they wanted to make the world a better place. Of these 90%, we see that 60% saw the possibilities for small actions on a local or individual basis and 30% of the children indicated that they felt they had good ideas and wanted to continue working on waste separate waste at their school [Figure 5].
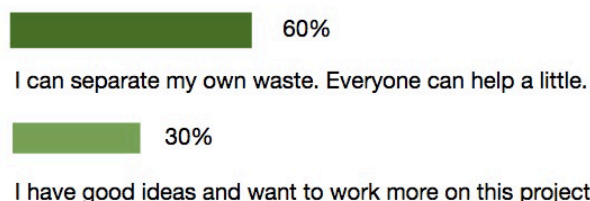

Figure 5: Answers of the 37 children to the question: 'Do you want to make the world a better place and how could you do that?'

"Every little bit helps towards a better world."
Chenoa, 10 years

"Because I have a lot of ideas that can help the world." Idris, 12 years.

These outcomes indicate that foundations are be-ing laid and/or reinforced, for the children to see themselves and begin to act as change-makers. Combining the motivation and creativity of these children with the right opportunity and support can guide them to become Change-makers, both now

and in the future. Further research on the effect of the Designathon method on the attitudes of these children will be conducted at the upcoming Global Children's Designathon on November 3rd 2018. Additional research is needed to estimate the effects on children's behaviour over time.

Comparative Case study 4: Kibera, Nairobi, Kenya and Amsterdam, The Netherlands

On the 7th of June 2017, in Nairobi, Kenya, students of the Nairobi Design Institute, together with two facilitators from Designathon Works ran a morning long Designathon workshop with 20 children aged 7 to 12 years who go to school in Carona Vision Centre in Kibera, one of the least well-off parts of the city.

The theme of the Designathons in Kibera and Amsterdam was 'Mobility, with the creative question: 'How can we improve mobility in our city?' Within the theme each group of children then further define the problem they themselves perceive around mobility. What immediately became apparent in Kibera was that the children were much less familiar with some of the information in the slides such as the reference to drones for example. Whilst the language of tuition at school in Kenya is officially English, much verbal exchange takes place in Swahili which is the mother tongue or second language of many of the children. This caused complications in the translation of explanations, where language gaps coincide with technological gaps such as the lack of drones; there being no Swahili word for drone at the time.

Figure 6: We made a device to keep us safe from drunk drivers. Tim, 10 years.

Another clear difference when compared to the same workshop and theme held in Amsterdam North at the Biënkorf School on the 14th and 16th of March 2016, was the sub-problems the children choose to tackle. In Amsterdam the children in group 7, aged 10 and 11 years, worked on problems such as traffic jams, air pollution by cars and improving the mobility of their grandparents. In Nairobi the children were concerned with the expense of transport to get into the city-center and with their safety while travelling. Many busses, known as Matatus which are privately owned drive at high speeds and cause fatal accidents. The children in Kibera were, when compared to their Dutch counterparts, hesitant to give their opinions and ask questions during the group discussion about the theme. Once the children got making with the recycle materials and the Maker Kit, they were as eager and active as their Dutch peers and worked together making prototypes. Without an exact scale to measure, the children in Kibera seemed more adept at working with electrical wires, motors and batteries. A possible explanation for this would be that many children would have makeshift electrical supplies at home or in their neighbourhoods which would give them more exposure to the workings of for example an electrical circuit.

Both the teacher and the school principal were very much in favour of giving the children experience with technology seeing it as a potential way for the children to overcome their disadvantaged circumstances. As in many contexts the teacher was also pleasantly surprised about the creative ability of his pupils.

Figure 7: 'I never thought the children could be as creative as they were'
David Olluch, Teacher, Carona Vision Center.

Case Study 6: Designathon School programs in the Netherlands and the journey to the classroom

Designathon School is a version of Designathon that has been extended for the classroom practice, it is accompanied by a teacher training and mapped to national curriculum learning objectives.

Through collaboration with some 60 Dutch Primary schools (between 2014 and 2018) in a variety of settings, we have observed that many teachers are enthusiastic to incorporate this approach into their educator's toolbox and engage their pupils' creativity.

"...When I looked around me in the classroom, I saw an almost 100% commitment by the children to their designathon projects. That never happens with reading, spelling or math." Inge Braam, teacher OBS de Kosmos, Apeldoorn

"It was fascinating to see how the children learned many technical skills while they were designing their machines, but above all there is room for the creative and interactive processes in a Designathon". Lieke Boven-Verheij, Laterna Magica, co-ordinator Unit 2, ages 4-6

Figure 9: Brenda, teacher and coordinator at De Bïenkorf with the Designathon maker kit

The reason for teachers' enthusiasm, seems to be twofold, firstly the high level of engagement and motivation demonstrated by the children. Secondly, but perhaps more importantly, teachers see the potential of Designathon workshops to increase creativity and the potential to offer obligatory curriculum subject matter such as that of geography, civics, nature studies (biology) in new and interdisciplinary ways. In the Designathon School workshop on "Mobility" for example, students grapple with physical phenomena such as kinetic energy, electricity and magnetism; they compare the relative advantages and disadvantages of types of transport from the perspective of the individual user plus the differing impacts of various forms of transport on our environment. In principle this is a perfect way for children to connect parts of vari-

ous core subjects through meaningful and creative projects. That being said the teachers we work with also have extremely limited time to undertake the professional development, lesson and material development they see as needed to employ such interdisciplinary methods and indeed familiarise themselves with the new technologies they would love their pupils to learn. In the majority of cases our school collaborations manifest in the form of a theme week, once or twice a year, albeit with the intention to expand. Clearly a more structural approach is needed.

The mentioned collaborations were initiated with a quite wide variety of aims. Some of the aims of teachers, schools and school groups include:

- engagement of children in sustainability issues;
- introduction of technological literacy in combination with art and culture programs;
- government mandates to give more attention to science in school [15];
- a perceived need to start offering what are known as 21st century skills;
- a wish to make a start with Maker Education;
or indeed some combination of all of the above.

Similarly, the collaborations are initiated from several different levels of school organisations, including individual teachers, gifted children programs, school boards governing 20-30 schools or through a regional expertise centre offering an available subsidy or program to experiment with new forms of science or technological learning in the classroom. A list of the schools and the school network organisations can be found here [16].

There seem to be several factors affecting the long-term sustainability of changes to classroom work, the most important being the (lack of) support of teachers. While it is beyond the scope of this paper to explore the current political contextual landscape, we read in Jelmer Evers' essay in 'Teaching in the Fourth Industrial Revolution', that diminished support for teachers' professional development and autonomy is on the line worldwide and this situation is certainly not restricted to the Netherlands [17].

For this reason we suggest that schools incorporate the changes to science and technology curriculum into their long-term plans. A good of example of such an approach in our view is the 'Actieplan Wetenschap en Technologie' [18] program of the City of Amsterdam, which provides programmatic support to work on structural impact in the school, to weave new pedagogical approaches with current curricular contents.

Projects such as that of Koen Timmers, Global Teacher Prize finalist, called Climate Action Project [19] involved 250 schools over 69 countries. This project like the designathon method also focuses on one or more SDGs as does much of Timmer's inspirational work. In the Climate Action Project, students around the world are connected, to 'explore, brainstorm, create, discuss, present and share their findings via weekly videos to be published on the website Timmers created. This way students learned from each other locally and in the next stage globally from their peers.' The fact that so many teachers sign up their students and it grows every year, demonstrates both the need and the possibilities for education which allows for the development of both students and teachers change-making abilities and agency.

The application of curriculum knowledge in the designathon approach is not limited to the domains of civics or geography but also during the making of prototypes. Here is where the Maker Movement becomes key: creating an object of original design according to a specific need facilitates opportunities for students to apply and eventually become literate in areas of science. These include, but are not limited to: properties of various materials; investigating construction with different materials and confronting the implications of science and technology on humanity.

Our conviction is that, by combining the spirit of the Maker Movement with the approach of Design Thinking, Maker Education can ground itself in an even broader purpose: that of opening the way to become part of curricula worldwide and empowering children to positively impact the world around them. It is by democratising this power of creation as a structural element in our classrooms that we can create a new generation of "changemakers" at our schools.

The introduction of change-maker Education is already happening as we speak. An opportunity on an previously unknown scale presents itself now for Change-maker education in the classroom: The Dopper Changemaker Challenge Junior [20]. Launched on the 22nd of August in the Netherlands, this Challenge has been offered free of charge to schools throughout the Netherlands. Its goal is to give children the classroom experience of tackling the global issue of plastic waste. The children will be guided in using the steps of Design Thinking to create a prototype on paper in the spirit of the Maker Movement by their teachers. There are some fifteen thousand children currently registered to participate in this challenge. On the basis of teacher and student responses we will attempt to find out if the students see themselves as Change-makers more after completing the Challenge and if teachers noticed a change in the engagement, knowledge literacy and creative application of their students.

CONCLUSION

The Organisation for Economic Co-operation and Development (OECD)[2] emphasises that a framework for future education must foster creativity as well as the responsibility for the consequences of one's actions[1]. If education today wishes to increase the agency of the young citizens of tomorrow, it is paramount we critically explore all avenues. As we have seen in the case studies, teachers, students and in some cases administrators recognise the possibilities to explore interdisciplinary learning of the type we envisage. Furthermore, there are a plethora of initiatives enticing educators to engage with global issues in the classroom

Given these new possibilities to marry education to the Maker Movement, while maintaining the mandates of both and to indeed to one day fulfil more of the dreams of thinkers on whose shoulders we all stand, such as Dewey, Papert and Freire, we believe that the weaving of the technological prowess of the Maker with the social good aims of the change-maker vision with core curricular contents is possible through a Design Thinking model.

As seen in the case studies, once the opportunity is created for children to see themselves as Change-makers, adults take the creative and collaborative capacity of children more seriously. How do we cultivate the abilities of children's agency, if we don't see children as capable of changing the world we live in and that they will inherit? We feel that this realisation is needed to change the adult-child paradigm in such a way to ensure that adults perceive children as shapers of their own future. In addition, schools and teachers must be supported by long-term planning, space for their professional development and funding by governments with a vision to facilitate both our current and future citizens to change the world for the better. With the Designathon method we make an attempt to contribute and in good iterative fashion will continue to learn and improve.

ACKNOWLEDGMENTS

REFERENCES

[1] The 17 Sustainable Development Goals, and the 2030 Agenda for Sustainable Development established by the United Nations. https://www.un-.org/sustainabledevelopment/development-agen-da/ retrieved on 20/8/2018.

[2] OECD (2018), The Future of Education and Skills: Education 2030; retrieved 19/6/2018 from oecd.org.

[3] Martinez, S.L. & Stager, G.S., Invent To Learn: Making, Tinkering, and Engineering in the Class-room, 2013, Constructing Modern Knowledge Press,Torrance (CA).

[4] Piaget, J., The construction of reality in the child (New York: Basic Books, 1954) [La construc-tion duréel chez l'enfant (1950), also translated as The Child's Construction of Reality (London: Routledge and Kegan Paul, 1955)].

[5] Papert, S., The Children's Machine: Rethinking School in the Age of the Computer, 1993.

[6] Beamer, E., Sallaerts, A., Conkic I. (2017). Co- design with Children on Societal Challenges Reveals their Empathy and Radical Innovations.

[7] Carlson, S. M., White, R. E., & Davis-Unger, A. C. (2014). Evidence for a relation between ex-ecutive function and pretense representation in preschool children. *Cognitive Development*.
[8] Singer, D.G.& Singer, J.L. (2005). Imagination and play in the electronic age. Cambridge, MA: Harvard University Press.

[9] Ashoka, https://issuu.com/ashokachangemak-ers/docs/more_than_simply_doing_good_definin; 2016, retrieved on 4/9/2018.

[10] Freire, P. (1993). Pedagogy of the Oppressed. New York, Continuum.

[11] Blikstein, P. (2013). Digital Fabrication and 'Making' in Education: The Democratisation of Invention.

[12] The 18 cities were, Amsterdam, Chennaa, Panjim, Dar es Salaam, Dubai, Dublin, Duisburg, Johannesburg, Clearwater, London, Milan, Montre-al, Vancouver, Nairobi, Singapore, Tel Aviv, Tunis and Zagreb.

[13] Global Voices of the Next Generation: Wa-ter https://docs.wixstatic.com/ugd/b179a6_

d6411104a2e944a694a971d8b75b8a5a.pdf retrieved on 20/8/2018.

[14] Beamer and Cuervo, 2018. Cultivating chil-dren's potential as change-makers: Notes on rethinking how society sees children's role in shaping the future.

[15] Rijksoverheid (National Dutch Government (2013). Techniekpact; retrieved 6/9/2018 van https://www.rijksoverheid.nl/documenten/conve-nanten/2013/05/13/nationaal-techniekpact-2020

[16] List of Schools which collaborate with Des-ignathon works: http://www.designathonschool.com/scholen/ retrieved on 20/8/2018.

[17] Doucet, Evers, Guerra, Lopez, Soskil, Tim-mers. (2018) Teaching in the fourth industrial revolution.

[18] Action plan Science and Technology https://www.amsterdam.nl/bestuur-organisatie/watdoet/arbeidsmarkt-regio/masterplan-techniek/projecten-masterplan/actieplan-wetenschap/ re-trieved on 4/9/2018.

[19] Climate Action Project. https://www.cli-mate-action.info/. retrieved on 4/9/2018. [

20] Changemaker Challenge Junior learning mate-rials for download, Dutch only. https://changemak-erchallengejunior.com/lesmateriaal/

Self-evaluation of learning activities by children in a library-makerspace
Development and validation of a visual instrument

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ABSTRACT

Learning activities in a makerspace are hands-on and characterized by design and inquiry. Evaluation is needed both for learners and their coaches in order to effectively guide the learning process of the children and for feedback on the effectiveness of the after-school maker activities. Due to its constructionist nature, learning in a makerspace requires specific forms of evaluation. In this paper we describe the development of an instrument that facilitates and captures reflection on the activities that children undertook in a library makerspace. Our aim is to capture learning in this context with multiple instruments: analysis of the artifacts that are made, observation of hands-on activities and interviews - which all are time consuming methods. Hence, we developed an easy to use tool for self-evaluation of maker learner activities for children. We build on the design of a visual instrument used for learning by design and inquiry in primary education. The findings and results are transferable (formative) assessment and evaluation of learning activities by learners in other types of education and specific in maker education.

KEYWORDS

Learner report, self-evaluation, maker skills

1 INTRODUCTION

Learning in makerspaces is informal and has multi-faced goals that depend on learners' personal interest, prior knowledge, etc. However, even in such informal learning environment, learners and coaches need formative tools for feedback (ideally followed by feedforward) on their progress. In order to 'grab' these multi-faced goals we developed an instrument that could easily be used by children in after-school activities in the library makerspace. Children should be able to use this instrument at the end of an afternoon, (almost) without help of the supervisors. Our aim is to collect these learner reports on a large scale at the end of a maker cycle in order to collect children's' experiences and to compare and triangulate with observations and analysis of artifacts. Thus, this instrument adds to the evaluation of learning in the makerspace.

1.1 Maker learning activities

Building on constructivism (Piaget, 1950; Vygotsky, 1978), constructionist learning theory (Papert, 1991) states that learners construct knowledge specifically when they actively participate in the making and sharing of a physical object (Papert, 1991). Cohen (2017) distinguishes four elements to be essential maker activities: creation, iteration, sharing, and autonomy. Although the specific knowledge learners construct by making is very diverse, there are

several scholars that have focused on identifying more general learning outcomes in makerspaces.

Bevan, Gutwill, Petrich, and Wilkinson (2014) observed participant learning activities in a museum-based tinkering program and identified four dimensions of learning: engagement (e.g., joy or frustration), initiative and intentionality (e.g., setting goals and overcoming failure), social scaffolding (e.g., sharing an helping) and development of understanding (e.g., explaining outcomes).

Chu et al. (2015) propose that making activities should be focused on developing a Maker mindset in children. They define three key determinants of the Maker mindset, i.e., self-efficacy, motivation and interest. Thus, preferred learning outcome of making activities should be a positive change in self-concept with respect to making, i.e., an increase in perceived ability ("I believe I can make things"), motivation ("I like to make things") and in taking initiative ("I want to make things"). Katterfeldt, Ditter and Schelhowe (2015) also state that activities in digital fabrication learning environments can facilitate a change of self (ic. Bildung). They summarized three core ideas for learning environments aiming at Bildung: begreifbarkeit (i.e., making connections between the virtual and physical world), imagineering (i.e., creating objects with personal meaning) and self-efficacy.

1.2 Self-evaluation

Introduced by De Groot in 1974, the learner report can be defined as 'an instrument to evaluate those learning goals, that are hard to evaluate in another way'. Through the years it has been used for several goals, especially as a didactical tool or instrument for evaluation of learning (Van Kesteren, 1993). A learner report consists of fill-ins that stimulate the learner to express what he or she has learned (i.e., about the content and about him or herself). The form can be open or closed. An open form may exist of open question and some sentences to complete ("I have learned that..."). Closed forms may submit statements about learning experiences and learners have to mark to what extend these apply to them.

The main inspiration that we used in the design of the learner report is the tool for self-evaluation of Ontdek-app, a digital learning environment for primary education that stimulates children to design and investigate. In order to make children conscious of their learning experiences, a visual instrument was developed in 2015, as shown in figure 1. This was inspired by various visual rubrics for assessment in art education (Maarleveld & Kortland, 2013; Redmond, 2004) and extensively tested and redesigned (Fraij & Zegers, 2016).

2 METHOD

In our research in the Amsterdam Central Library

makerspaces (Pijls, Kragten & Van Eijck, 2018), a learning report will be used for self-evaluation of the learning goals as defined by the organization. This instrument contains closed statements (on the form's front side) and open sentences (on the form's back side). This choice was made because the makerspace mainly focusses on primary school children and a tool that would depend too much on language and writing would not be effective. We wanted the learning report to be approachable, intuitive and fast. Furthermore, we decided to submit statements that refer to activities in the makerspace and hypothesize that these activities represent learning experiences. For example, a child that reports to have helped other persons will have enhanced its social skills from that activity.

The learning goals of the makerspace are structured in three domains technology, socialization and subjectification (Biesta, 2014) and are closely related to the learning activities mentioned in paragraph 1.1. The first domain, technology, stands both for creating artifacts with digital fabrication, electronics, programming and for inventing and designing new prototypes, generating ideas, indicated as creativity (Buisman, Van Loon-Dikkers, Boogaard, van Schooten, 2017). The domain of socialization consists of helping others, asking for help, being engaged with the social and material environment. Subjectification has to do with motivation, empowerment, self-efficacy, self-expression and persistence. We operationalized those goals into seven categories (Table 1) and therefore formulated seven statements (items) to evaluate children's learning experiences.
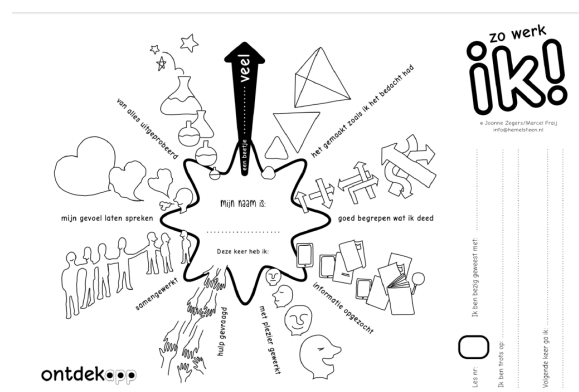

Figure 1: Self-evaluation instrument for students, Ontdekapp

Our research question in this design research was to develop a visual instrument that enables learners to reflect on their activities in the makerspace and to become conscious of their own learning in the domain of technology, socialization and subjectification.

The study was typically a design research (Mc Kenney & Reeves, 2012). The design process was carried out by a team of three researchers, a graphical designer and a research-assistant. The

expert group of designers and coaches of the project acted as critical friends.

The design research consisted of two design cycles and a third cycle will be carried out. First, a rough draft of the learner report form was presented to five children in order to test whether the visual invited children to color and whether they used different gradations. Then the design requirements were sharpened and the graphical designer made the first prototype. The first prototype was tested with five children and presented to a team of experts. This feedback led to some adaptations, which were carried out by the graphical designer. The second prototype was tested again in a validation session with children. In this session the answers in the learner reports were linked to observation and interview data in order to validate the items. The results of this session led to adaptations, which were made in the third prototype. The results of the third prototype will be presented in the conference session.

Table 1.

Domain	Category	Item
Technology	Creating	'I made something'
	Creativity	'I invented something new'
Socialization	Social scaffolding	'Another person helped me'
	Social scaffolding	'I helped another person'
Subjectification	Intrinsic motivation	'I liked it'
	Self-efficacy	'I can make it'
	Persistence	'I did carry through'

3 DESIGN CYCLES

3.1 Design requirements

The design requirements of the learner report form are:

1) It can be used by the children independently without too much explanation by the coach;

2) Minimally dependent on language and writing skills;

3) The symbols are 'hollow' and invite for coloring;

4) Children write their (nick-)name in the middle of the paper, to make it personal;

5) The item are represented by a symbol and a matching statement;

6) The symbols are small in the middle and become larger towards the periphery;

And some extra requirements:

7) The general image must be 'quiet';

8) The symbols must match the corporate identity of the makerspace;

9) In the final design each symbol will be represented five times;

10) The design anticipates on a digital version in future.

The backside of the learner report form contains open questions about learning experiences that could not be captured with closed statements:

- Date;

- What the child has been doing ('I worked on....');

- What the child is proud of ('I am proud of...');

- The intention for the next time ('Next time I will...').

3.2 First prototype

The first prototype was tested with five children in the makerspace. This yielded in two main remarks. First, it was concluded that there were differences in the way the children colored the figure. In the next design cycle we aimed to validate these differences with help of observations. Secondly, it also happened that children did not color in the symbol, but that they encircled the symbols. That is why we considered other symbols for the next prototype.

3.3 Second prototype – analysis per child

The second prototype was tested with seven children. They filled in the learner report form at the end of an afternoon in the makerspace and the results were first triangulated by interviews with the children.

The visual of child #1 - in Figure 1 - has high scores on all categories. In the interview child #1 shows enthusiasm "I like it very much with other kids here" and mentions that it often helps other kids, for example 'if anyone cannot get the thread in the needle'. This child also includes earlier experiences in the makerspace in its evaluation, for instance with the item 'Another person helped me', where is

says 'not this time, but if I do not manage, then yes'. It also mentions that one of the things it is making is 'super difficult' so that it learns new things and says 'I have to persist, I want to finish it, so I have to work very hard.' and finally 'I learned a lot, that is why I can do better now.'

The visual of child #2 – in Figure 2 - also shows enthusiasm and states in the interview that 'I always like it'. This child is coloring the lowest score for both social scaffolding items and states 'I always work alone', 'It is only the teacher who helps me'. The scale for the item 'I made something' is used in linear way as the child indicates that 'the little bag [that I made, ed.] is almost ready'. The item 'I invented something new' is colored on the highest score, while the child mentions 'I did not invent anything by myself', so we conclude that the item is not valid. The items on persistence and self-efficacy have the highest score and the interview makes clear that the process was not easy, but that the child wanted to finish it and has the confidence to succeed.

The visual of child #3 - in Figure 4 - shows high scores on intrinsic motivation, self-efficacy and persistence, relatively low scores on social scaffolding – although in the interview the child mentions 'I rather often help other children'. Probably the item 'I made something' is again interpreted linear, indicating the progress of the making process of a certain artifact.

The visual of child #4 – as shown in Figure 5 – contains high score on all items, except the item 'Another person helped me'. The child explains 'I understand everything, I do not need a lot of help', which makes it remarkable that still such a high score is colored. The explanation for 'I helped another person' is 'I do help a lot, I like to help other people, they learn from it.' All other items do have explanations that support the high score.
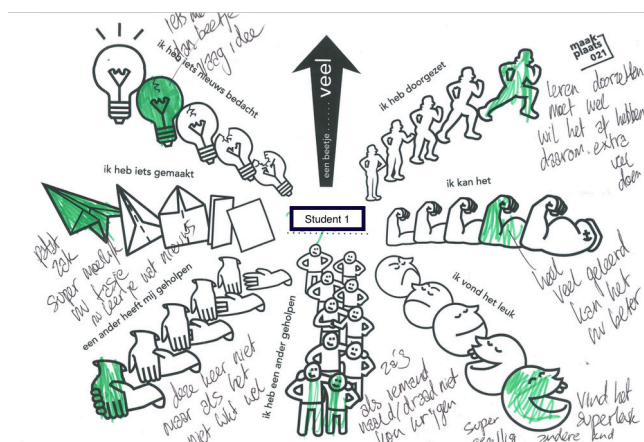

Figure 2: the instrument of child #1

The visual of child #5 – as shown in Figure 6 – is in line with the previous visuals: many high scores. And the explanation support the idea that the process of making is not easy,

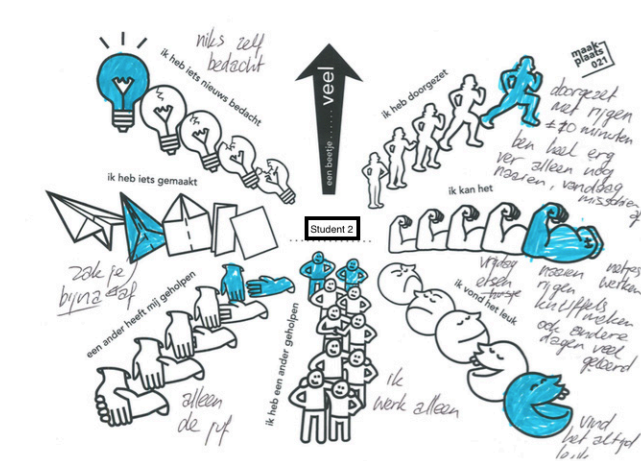but that the child persists and likes to do so.

Figure 3: the instrument of child #2

The visual of child #7 – shown in Figure 7 - contains a high score for intrinsic motivation, with the explanation 'I like it, although it is not really my hobby'. This child has low scores on social scaffolding and mentions that giving and receiving help does not occur so much. This child has the lowest score on 'I invented something new', although it mentions that it has designed a bag. The item for persistence is colored with a score 4 and the child explains 'This time I persisted, I did not become so angry'.
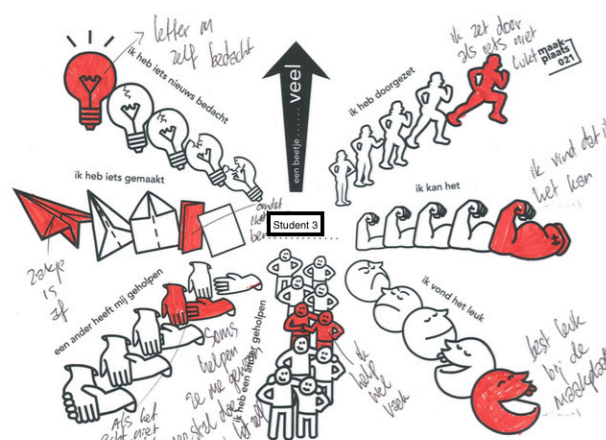

Figure 4: the instrument of child #3

The visual of child #7 – shown in figure 8 – shows a 4 for intrinsic motivation, the item 'I liked it' and the child mentions that 'sometimes it is rather busy'. This child has the greatest difference between giving (high) and receiving (low) help. Remarkable is the explanation of the middle score for 'I invented something new', namely 'Nothing original'.

3.4 Second prototype – analysis per item

The results for each item of the learner report were as follows:

'I invented something new'

This item operationalized creativity and inquiry.

The majority of the scores were 4 or 5 and children explained that they choose a lower score when
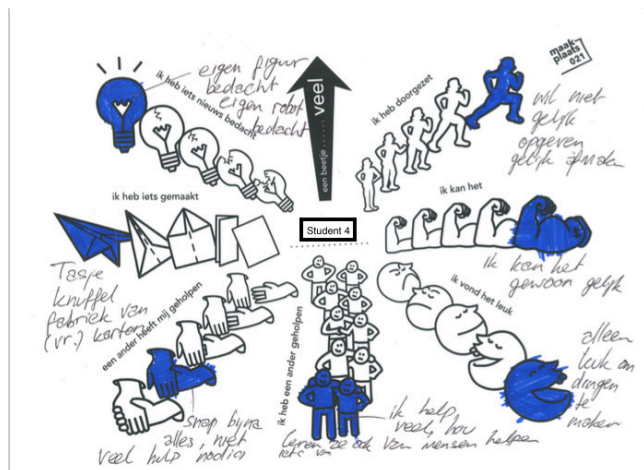

Figure 5: the instrument of child #4

they invented, 'something' or 'nothing original'. An explanation for the lack of low scores, might be that the broken lamp is not attractive to color in. In the observations, no evidence was found for inventions by the children. This item seems to be valid, although the symbol of a broken lamp might
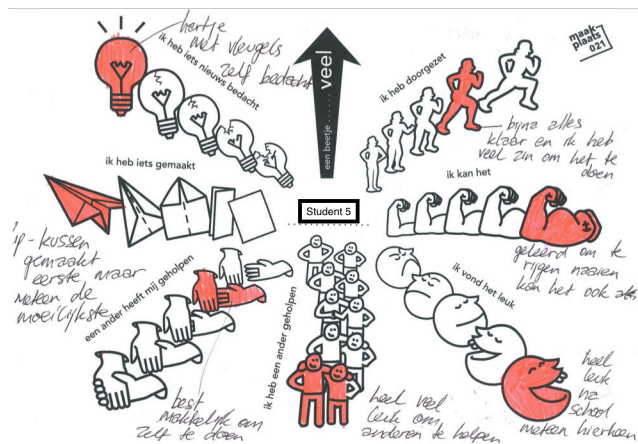

Figure 6: the instrument of child #5

better be replaced by a whole lamp.

'I made something'

This item operationalized maker skills. The majority of the scores were 4 of 5 and children explained how they made something or what they made. Especially they explain how far they came with their making. This coincides with the fill-in on the backside of the learner report. The findings do match with the observations, were children were making something. This item is not valid for measuring to what extend children were making, it hardly adds information. So it will be replaced by another visual and another item, 'I learned something.'

'Another person helped me'

The average score is 2,5 with a minimum of 1 and a maximum of 5. Children explain that they have

Figure 7: the instrument of child #6

hardly been helped by others, or 'only by the teacher'. This was confirmed by the observations. In order to separate instruction by the coaches from peer learning, the adaptation will be 'Another child helped me.'

'I helped another person'

The mean score was 3,7, with a minimum of 1 and a maximum of 5: the majority of the students mentions that he or she is helping from time to time. The observations confirm that children with
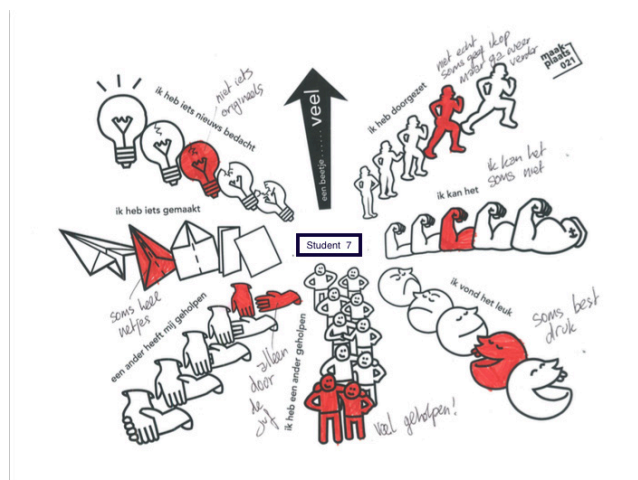

Figure 8: the instrument of child #7

high scores were helping often and low scores were helping a bit. No adaptations to this item.

'I liked it'

The mean score was 4,8, minimum 4 and maximum 5. All children give the highest score, apart from one child that gives a '4, because sometimes it is rather busy'. The observations show that the children are working, talking, laughing, no quarrel was observed. No adaptations to this item.

'I can do it'

The mean score is 4,2, minimum 3 and maximum 5. Two children give a '3' because they think they

'have learned a lot' and a 5 because they think they 'can make it'. It seems that this item does not measure self-confidence or self-efficacy, but rather learning experiences. We propose the adaptation 'I dare it'.

'I did carry through'

The mean score was 4,5, minimum 4 and maximum 5. All children give a 4 or 5 and explain afterwards why. The program seems to be quite challenging for children. The observations show that the majority of the children asks for help more than once. This could confirm the challenge of the activity. No adaptations to this item.

3.4 Third prototype

The third prototype is designed with all adaptations for the items and the requirement that the lay-out will fit the corporate identity of the makerspaces. This prototype will be tested with a group of 30 children. We intend to present the results of this tests at the conference in September 2018.

4 DISCUSSION AND CONCLUSION

What have we learned so far? We aimed at an instrument for self-evaluation of learning activities by children in an after-school context in a library maker space. The instrument consisted of a visual tool and a learner report. The learning goals (technology, social scaffolding, subjectification) were operationalized by seven items, which were visually represented in a coloring picture. The visual was attractive to fill in and most of the items yielded enough variation in answers. The items that represented maker skills were not (yet) valid in this visual; the items representing social scaffolding were valid and the items representing intrinsic motivation, self-efficacy and persistence.

The library maker spaces are still developing, this influences the learning activities that are stimulated: thus, the instrument evaluates both individual learning and learning environment. The instrument might help coaches and children to discuss the children's learning activities.

Further calibration is needed to have a valid instrument for evaluation of the learning at large scale in the network of library maker spaces. Currently a system of badges is developed in the makerspace, in order to value maker skills and social skills for the children. Evaluation of the technological maker skills might be connected to these badges, whereas the visual and learner report capture children's learning experiences. Thus, this learner report may help coaches to provide children feedback and feed forward and help them to develop as makers.

REFERENCES

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015). Learning through stem-rich tinkering: Findings from a jointly negotiated research project taken up in practice. Science Education, 99(1), 98-120.

Biesta, G. (2014). The beautiful risk of education. Routledge.

Buisman, M., van Loon-Dikkers, L. Boogaard, M. & van Schooten, E. (2017). Stimuleren van creatief vermogen en kritisch denken. Amsterdam. Kohnstamm Instituut.
Chu, S. L., Quek, F., Bhangaonkar, S., Ging, A. B., & Sridharamurthy, K. (2015). Making the Maker: A Means-to-an-Ends approach to nurturing the Maker mindset in elementary-aged children. International Journal of Child-Computer Interaction, 5, 11-19.

Cohen, J., Jones, W. M., Smith, S., & Calandra, B. (2017). Makification: Towards a framework for leveraging the maker movement in formal education. Journal of Educational Multimedia and Hypermedia, 26(3), 217-229.

Fraij, M. & Zegers (2016). De Ontdekapp. www.ontdekapp.nl geraadpleegd op 8 augustus 2018.

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

Kesteren, B.J. van (1993). Applications of De Groot's 'Learner Report': A tool to identify educational objectives and learning experiences. Department of Agricultural Education, Wageningen Agricultural University, Wageningen, The Netherlands.

Maarleveld, O. & Kortland, H. (2013). Beeldend reflecteren: een nieuwe beoordelingsmethode voor praktisch beeldend werk in het Voortgezet onderwijs. Amsterdamse Hogeschool voor de

kunsten. Amsterdam. The Netherlands.

Mc Kenney, S. & Reeves, T. (2012). Conducting educational design research. The Netherlands: Taylor & Francis.

Papert, S. (1991). Situating constructionism. In S. Papert & I. Harel (Eds.), Constructionism (pp. 1–11). Norwood, NJ: Ablex.J. Piaget, B. Inhelder, The Psychology of the Child, Basic Books, New York, 1969.

Piaget, J. (1950). The Psychology of Intelligence. New York: Harcourt Brace.

Pijls, M. , Kragten, M., van Eijck, T. (2018). Maakplaats 021. Praktijkonderzoek naar het verwerven van vaardigheden voor de toekomst door kinderen in Amsterdamse buurten in maakplaatsen bij de openbare bibliotheek. Kenniscentrum Onderwijs en opvoeding, Lectoraat Didactiek van de Betavakken, Hogeschool van Amsterdam.

Redmond, C. (2004). The creativity wheel. Retrieved on 6 July 2018 from https://irresistible-learning.co.uk/

Vygotsky, L.S. (1978). Mind in Society. Cambridge, MA: Harvard University Press.

Purposeful Prototyping through a Discussion Game in Primary Education

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Figure 1. Discussion game on prototyping goals

ABSTRACT

Working with prototypes is an important aspect of designing, however novice designers may lack intentionality during the prototyping process. As a result, time is wasted on irrelevant elements or testing of the prototype does not yield a lot of information to forward the design idea. When novice-designers learn that prototypes are simplifications of design ideas to test specific goals, this may result in more useful prototypes. In a biomedical design project by 10-12 year olds therefore an intervention was developed and tested to increase intentionality in prototyping. The pupils played a prototyping discussion game before they started prototyping. As a result, they became acquainted with a diversity of testing goals and prototypes. They were also asked to select a testing goal prior to building their own prototypes. The pupils learned that a focus is needed in prototyping and were able to develop heuristics to select a goal. The specific testing goals supported decision making on where to go next in the prototyping process. Some revisions to the game and intervention are necessary.

KEYWORDS

Design and Technology Education, Prototyping, Formative Evaluation, User centered design

1   INTRODUCTION

Design and technology education is about designing artefacts and services that have a function and value for people. A variety of skills are developed by the learners such as creativity, empathy and cooperation (Klapwijk 2018).

Working with prototypes is an important aspect of designing (Wall, Ulrich and Flowers 1992) and enables designers to test the functioning of the prototype in real life and to detect its strengths and weaknesses. The critical value of prototyping is also shown by Shrage (1993) who discovered that (many) breakthroughs made by engineering designers are dependent on the designers ability to experiment and test concepts.

It is therefore not surprising that many countries include prototyping in the curricula for Design and Technology Education (International Technology Education Association 2007; Ministry of Education of New Zealand 2007; 2010).

However, for professionals as well as novice designers, it is often not easy to use prototyping effectively (Deininger e.a. 2017; Menold e.a. 2017). Many teachers in primary and secondary schools report that pupils are often not focusing on the right things during the prototyping process. Due to the lack of sound goals, prototyping processes often do not achieve their full potential.

To solve this problem, a prototype-discussion game was developed by the second researcher to make pupils acquainted with the various prototyping goals and prototypes.

In this paper we report on the application of the game in a biomedical design project by 10-12 year olds. The focus in the our case study is on how playing the game helped pupils to select and formulate testing goals for their own project and how these specified goals influenced the intentionality of the prototyping process.

2 THEORY

2.1 The nature and goals of prototyping

Prototyping is a form of modelling (Nia and De Vries 2017). In science modelling is used to explain the world, in design and technology models have a different function and are meant to learn about attempts to intervene in the world (France e.a. 2011).

Typical for prototypes is that they are not the real thing yet, but they are realized prior to the implementation of design outcomes (France e.a. 2011). The prototype will differ in one or more major aspects from the final outcome and are not meant for final use. They render reality or parts of reality (Nia and De Vries 2017).

Prototypes of technical artefacts have a materiality and exist outside the human mind (Nia and De Vries 2017). They range from low fidelity (simple models) to high fidelity ones (almost fully functioning and very similar to the real thing). Prototypes are often 3D-embodied artefacts but may have a 2D-nature. For example, to test a computer game with future uses one may show a user series of screenshots of the intended game. Sketches used to test, explore or communicate an idea also function as a prototype, e.g. a floorplan of a new house (Deininger e.a. 2017).

It is broadly agreed that prototypes help to reflect on what is happening in the design (France e.a.

2011). According to Schön, prototypes are meant for reflection-in-action, unique and uncertain situations are understood through attempts to change them and changed through the attempts to understand them (Schön 1983; 1988; Baaki et al. 2017).

Prototyping allows the designers and other stakeholders to test some crucial aspects of the design idea at a lower cost than building the real thing. The direct feedback is used to uncover differences between real behavior and prior expectations (Jang & Schunn 2012; Lemons et al 2010).

In the literature three categories of testing goals are described: testing for technical feasibility, social desirability and economic viability.

Technical feasibility: Some prototypes are meant to test mechanical or technical working (Boon and Knuuttila 2009). Technical testing and reasoning is about "how it is happening"

Social desirability: Other prototypes are meant to study the interaction of users with the prototype and the social desirability of the product (France e.a. 2011; Nia and de Vries 2017). This is about "should it happen?" (France et. al) or "does the user want this to happen". The division of technical feasibility and social desirability relates to the dual nature of technological artefacts (Kroes and Meijers 2000).

Economic viability: These prototypes are used to test if the artefact economically viable and ready for (mass) production (Menold e.a. 2017).

Prototypes are often multifunctional. Besides testing, they are used for thinking (Jang &S Schunn 2012) deciding (Menold e.a. 2017), communicating and storing ideas. Designers use prototypes to communicate with other designers, clients or stakeholders about a design idea and to think collectively about a design (Jang & Schunn 2012). Prototypes are autonomous agents they can be handed over to someone else or can be stored making a-synchronal communication possible (Nia and de Vries 2017; Van der Lugt 2005).

When is a prototype considered good? Nia and De Vries (2017) state that there is a sort of general agreement in this regard, that models – including prototypes - are not really intended to be 'accurate', 'true', nor should they be judged on 'the degree of similarity' to the real thing; Something else is important, namely the 'adequacy-for-purpose' (Parker 2011; Nia and de Vries 2017). Is the model adequate for the intended purpose?

2.2 Using prototypes in design education

In design and technology education, students have to learn to make prototypes that are fit for purpose. Based on our own classroom experiences and reports on prototyping in primary schools (Kangas e.a. 2011; McFadden and Roehrig 2018), prototyping consumes time and energy. Although we need to realize that protyping will always take time (Sennett 2009; Looijenga et al 2018), many teachers that we have met through the Delft Science Hub mention that time is often wasted on "wrong" and "irrelevant" prototyping actions, e.g. spending time on a logo or on appearances. This finding is supported by the literature and is also present in higher education. Deininger e.a. (2017) interviewed novice engineering students in a project-based senior-level design course and discovered that these students – conducting one of their first design projects - lacked intentionality during prototyping.

In comparison, studies on best prototyping practices suggest that designers ask specific questions that they then try to answer with the help of prototypes (Camburn et al 2015). Students thus need more support to develop a sound prototyping focus. Deininger e.a. (2017) propose that instructors ask questions prior to building prototypes to make the prototyping process more intentional. Also, there is ample scientific evidence that sharing and clarifying learning goals in classrooms greatly improves the learning results (Wiliam 2011; White and Frederiksen 1989). In analogy, knowing where you are going in a prototyping process will have similar value.

A game was therefore developed by the second author to provide primary school pupils with a playful way to become acquainted with various testing goals and a diversity of prototypes. The aim of the game was to provide pupils with a better foundation to discuss and to specify testing goals and use these in subsequently in a prototyping process. Our central research question is:

How does playing a prototyping-discussion game prior to building prototypes help pupils (10-12 year olds) to understand, discuss and select goals for prototyping? How do the design teams deal with these goals during the prototyping process?

3 INTERVENTION AND RESEARCH METHOD

3.1 Participants and research method

The study took place at a primary school in the Netherlands, in the area of Zuid-Holland. One class of a Dutch primary school participated over a period of six weeks in September and October 2016. The class consisted of 22 pupils in a mixed class (grade 7 and 8) who were approximately 10 to 12 years old. The class had participated in one design project on fashion prior to this one. The class was divided into 6 design teams of 2 to 6 children.

3.2 The biomedical design process

The prototyping discussion game was played midway a biomedical design project, just before the design teams started to build prototypes.

In the first session, the design assignment was introduced by the teacher and presented as follows: "Design something that helps grandmother Tina who suffers from rheumatism, during daily activities." The pupils conducted simulations to experience the difficulties someone with rheumatism experiences. Next, the pupils formed six design teams and each team selected their own design problem, e.g. peeling potatoes or reading a heavy book. The teacher allowed the class to vary the team size.

Table 2: Overview of the design activities

Step	Activities
1 Exploring the design problem	- Doing simulations: sticks connected to fingers to simulate rheumatism - Who is grandmother Tina: creating a mindmap - Defining a specific design problem
2 Generating and selecting ideas	- Brainwriting: generating many ideas - Idea selection
3 Elaborating concepts	- Working on details of the chosen idea - Generating and answering questions to understand their design
4 Intervention: Prototyping-game	- Explanation of the game - Playing the game - Selecting goals for own prototype - Prototyping and some testing
5 Prototyping and testing	- Prototyping and testing
6 Presenting design and process	- Demonstration and exhibition of design outcomes

During session two, divergent thinking was central and many ideas were generated. Each team selected one design idea and elaborated this idea in session three but did not start to make it yet. In session four the intervention took place – playing the game, selecting a specific goal and prototyping. For an overview of the complete biomedical design project, see Table 2. All activities were facilitated by their own teacher who got instructions beforehand from the researcher.

3.3 The intervention: a prototyping-discussion game and selecting goals

In the developed game pupils are asked to relate pictures of prototypes with cards showing a

possible testing goal and to discuss their ideas with the other players. During the game, each team will first turn a picture card with a prototype. Next they individually select a goal card from a hand stock of five cards that matches the prototype best and put this card on the table. When none of their goal card matches well or when a number of cards fit, they should select the one that they think matches the prototype the best. All the cards on the table present a potential goal that can be tested with the prototype. The pupils will then be asked to select collectively the most fitting one from these through a discussion.

The second author selected testing goals in the technical feasibility and social desirability area that are as concrete as possible but can still apply to prototypes in various design domains such

Table 1: Goal cards

as architecture, games, digital devices, clothes etc.. The goal is written down as a question and visualised. See figure 2 for an example of the goal cards.

Type of testing Goal	Description of the goal on the goal cards in the game
Technical feasibility	- Does it work?
	- Do the parts fit together?
	- Is it strong enough?
	- Are the dimensions right?
Social desirability	- Is it comfortable to use?
	- Does it hold comfortably?
	- Does it look attractive?
	- Does it look professional?
	- Does it look funny?
	- Does it look cheerful?
	- Is it clear how it should be used?
	- Is there a market for it? Are people going to buy it?
Combination of technical and social elements	- Is it safe to use this product?
	- Does it fit in with the rest of the assortment?

Pictures of prototypes were collected that match specific goals and are from a range of design disciplines. Due to the design requirement of familiarity, many products are from everyday life. The prototypes are varied, but sketches, paper and computer animations were not included, the game focused only on tangible prototypes. Prototypes made by professional designers, university students and primary school pupils were included. For example, the form study prototype of the telephone was included and could be matched to the goal "is it pleasant to hold". In the game only 3D prototypes

of technical artefacts were included. No complete overview of the pictures can be given in this article due to space limitations. See appendix 1 for an overview the design requirements for the game.

3.4 Data collection and analysis

A qualitative research approach was used. Data were collected during session four about playing the game, selecting a prototyping goal and making prototypes using video and audio. Two design teams were especially followed, team 1 consisted of four girls, team 2 consisted of four boys. A central camera was used to capture the teachers
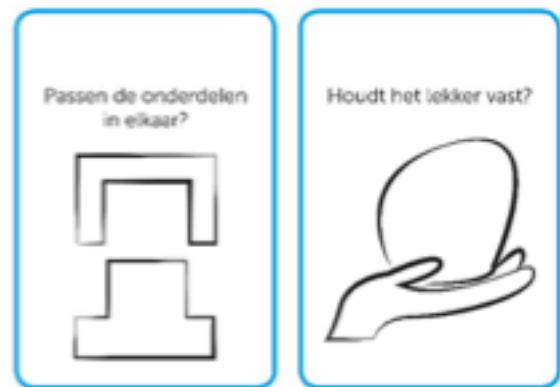

Figure 2. Example of goal cards " Do the parts fit together?" and "Does it hold comfortably"

instructions and some information about other teams was gathered. Pictures of prototypes were made at the end of session 4. The second researcher was present as observer and made notes.

Pre- and post-interviews were held. Interviews with nine pupils, one or two from each design team, took place between session 3 and 4. Post-interviews with at least one pupil from each team were held. All interviews took place in groups of two to four pupils. A post-interview was held with the teacher.

Open coding was applied. Some of the categories developed by Menold e.a. (2017) for analyzing university students views on prototyping were present in our data: speed, material, test and users. During the selection of a test goal additional more refined categories were developed to describe the selection heuristics: importance of goals, uncertainty of knowledge, hierarchy of goals, making an impression and available materials.

4 RESULTS

4.1 Intuitive ideas about prototyping prior to the intervention

To understand the intuitive ideas of the pupils the researcher interviewed the pupils prior to the

intervention with the discussion game. The teacher had only told his class that the next step would be to build prototypes.

The interview started with telling about the solution that had been selected for elaboration (session 3), next the interviewer asked "have you done any thinking about your prototyping?".

The responses show that various ideas about prototyping exist in this classroom. Pupils may point to the materials used "*We are going to use carton instead of real knives*", "*using clay is the most convenient*" .

Pupils refer to the speed of the process , e.g. "*The prototype is the quick way of working, for the real work you need to use more time*".

Pupils saw prototypes are representations of the real thing that are not necessarily accurate. "*Prototyping is possible on a computer, it does not have to work*". A prototype "*does not have to function necessarily*", but "*it would be nice if it functions*".

Various goals for prototyping are described in response to an open question about it, e.g. to "*see how it looks like*". This refers to the goal of thinking and reflection-in-action that professional designers practice (Schön 1983). Other pupils mention getting information about failures and redesigning, e.g. "*You can see were you run into*" or it is done "*to improve*".

None of the pupils mentions explicitly goals related to technical feasibility but goals related to social desirability were explicit in the interviews, e.g. "*Yes, how it is for people with rheumatism*" or " *If it (the design) is not too heavy*?". Children at this age thus understand that prototypes are meant for testing in a social, user oriented direction. The ability to come up with ideas about testing for social desirability might be induced by their prior work in the biomedical design project, e.g. simulating rheumatics and thinking about the needs of " grandmother Tina".

Overall, the 10 to 12 year olds were before prototyping started aware of some of the characteristics of prototyping such as the use of cheap, easy available materials and that prototypes are not the real thing. These intuitive ideas of pupils are rather similar to those found among engineering students (Menold e.a. (2017); Deininger e.a. (2017).

4.2 Playing the discussion game

Various types of dialogue were identified during the playing of the game.

When the prototype cards were turned out, pupils in team 1 and 2 are actively involved in figuring out what the picture is about and show genuine interest in the prototype examples. A lot of exclamations are given Oo! Wow! when they turn the card and see the prototype. For example:

René: "*eh, a horn of a telephone*".

Marc: "Wajo (word showing excitement), that is a prototype of a telephone!" .

Ella figuring out what the prototype is about:

"*What is this? A sweater and bag in one.*"

They also explain to other team members what the picture shows:

Mary: "*This is a scale-model of a building*".

Anna: "*Ooo, thus this is a small building*".

Through the game, they see a lot of prototypes and try to make sense of them.

The pupils in team 1 and 2 also comment on the low fidelity of some of the prototypes on the picture "*Yes, it really doesn't look well*", "*It is a bit strange*". A number of times they tend to think less of a prototype when it does not look nice – both during the game and as we shall see, also later on. This is consistent with Blikstein (2013) observation that pupils tend to prefer aesthetically pleasing prototypes.

As each pupil has a own hand-stock of five goal cards, they all individually select a goal matching the prototype on the picture best. At this point of the game, they - generally speaking – did not communicate to their team what they were doing, but some pupils use utterances that showed "deduction behaviour".

"*This one not, this one not, this one not*".

"*And this one, <u>does it work</u>? No.*"

Or they forward a goal-card in their hand as a possibility:

 "*I think <u>does it look attractive</u>*".

Or they indicate that none of their goal cards matches the picture:

"I have nothing at all that fits with it".

During this selection process, the video's and observations of the researcher and teacher, indicated that all pupils were actively involved in selecting goal cards.

In many instances, the selections made by an individual were not discussed. On other instances, an exchange about the goal takes place, but these exchanges are in general quite short.

Ella "*I have, is there a market for this product*?"

Mieke: "*Yes, me too!*"

Figure 3. Post lock for bikes

Explicit arguments for choices are not often given. The pupils, do however, give arguments for their choice on a number of occasions. Selecting cards with design features that the prototype is lacking was common in both teams. For example, when a child looks at a post lock, figure 3, it tells the teammates: "*I selected are the dimensions right because the stave looks a bit long*".

Or when a team looks at a pinball machine, figure 4, one pupil, Mary, puts down a goal card and says "*I have does it look cheerful? It does need some colours or so*". Another girl reacts with "*When I am in café, I would not think…this is a fun – a pinball machine. I mean you may use paint when you prototype*".

What we see here happening is that pupils check if the prototype on the picture fulfils this test criterion when they read the question on the goal card, e.g. are the dimensions right. When the prototype did not achieve the goal, they selected the goal card. They made the pair goal-prototype thus in a different way than intended by the game-developer.

The relative absence of dialogue on the goals is partly caused by the fact that the two teams did not collectively select the best matching goal most of their playing time. In team 1 (the four girls), one of the participants concludes that "*They all fit*" when they look at the first prototype-picture and collects all goal cards to move on to the next picture without any discussion. This becomes the habit in the next rounds. However, this team clearly reject some goals as not fitting, e.g. I *am doubting, there is not holder (of the telephone) with it*"

Team 2 (the four boys) directly forgets to select collectively a card from the four goal cards and only

in the last round the teacher joins in with this team and asks them to explain to him if the selected prototype can be used to test the goal "is it strong enough?".
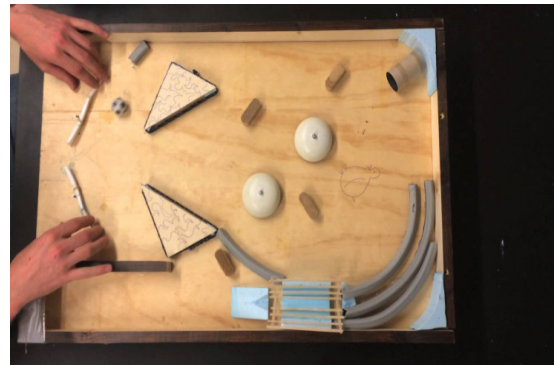

Figure 4. Pinball machine

What can we conclude? The game was successful in showing a lot of prototypes to the pupils and also in actively involving them relating these to possible goals. They kept on playing the game, moving enthusiastically to the next picture and checking their hand-stock for matching goals. However, three problems arose:

1. They hardly exchange arguments on their choices and do not learn from each other. This is amongst others caused by the fact that they do not collectively select the best matching goal.

2. They base their choices on design features that a prototype lacks as they use the question on the goal-card to evaluate the prototype. Instead of thinking, the prototype does not focus on this goal, they think the prototype does not pass the test.

3. Adaptations to the game and to the instructions given to the pupils about how to play the game are therefore needed, see section 5 for the changes we consider.

4.3 Selecting design goals prior to prototyping

The next assignment for each design team is to pick one key goal for their own prototyping process and if they want they can select two additional goals that are desirable to reach as well, see figure 1.

Prior to session four, team 1 had decided on making a pan to cook and cut potatoes and team 2 had decided to build a "bookchair". This is a special chair – the elbow rests will support the book and will enable grandmother Tina to read a heavy book.

Both teams took a set of prototyping goal cards and directly start to discuss goals for their own process. Similar to what they did in the game, they show deduction and selection behaviour as they check the goal cards. Sometimes without arguments, but

often they are involved in a group dialogue. These dialogues show several types of reasoning:

1. They look for what is important and what not

2. They look for things in the design idea they do not yet know how to make or if it really works and things they already know

3. They relate goals to the materials that they want to use

4. They think about how to make a good impression with their prototype

5. They look for a hierarchy in the goals

Ad 1. They look for what is important or unimportant in the prototype:

Girl 1: *It needs to be strong*

Girl 2: *It got to be strong.*

Girl 3: *But we are going to make a prototype what is not really to look if it is strong.* (Team 1)

Ad 2. They look for goals related to things they do not yet know and have to figure out:

Girl 1: Do the different element fit together is the most important one.

Girl 2: yes, because we need to think about how we pull this thing out (Team 1)

Once a pupil mentions that they do not have to select a certain goal for prototyping because they are already sure that their idea meets the goal.

Boy 1: And is it safe?

Boy 2: No, not this one ...it it anyhow safe.

Other boy: No, you don't know that.. (Team 2)

Ad 3. They relate goals to the materials that they want to use

The girls team has already decided prior to session four on some of the materials that will use to build the prototype and this influences the discussion as follows:

Girl 1: Or select is it safe?

Girl 2: Yes, but if you pour hot water in it?

Girl 3: But it is from carton (Team 1)

And another fragment*: " But this one as well (indicating the goalcard does it look cheerful with gestures) because we use a carton box to make it"* (Team 2)

They start here with the choice of materials and then discuss which goals can be tested.

Ad 4. They think about how to make a good impression with their prototype

Pupils also discuss how they can make a good impression.

Girl 1 *Because when. it looks very ugly....*

Girl 2 *Yes, just as with those children, the table*

Girl 3 *Imagine a company looking at it, if you get something like this or this. Then you will sure select this one because it looks neat (Team 1)*

In this example they refer to a prototype they know for the discussion game and that they look down upon.

However, later on team 1 shows that they understand that their prototype does not have to look good at any price. They understand that other goals are more important to achieve. This is a great lesson learned and may – later on- make the prototyping process more effective.

Girl 1: Our pan doesn't have to look as if it comes from the Hema (Dutch department store)

Girl 2: Now, it should look a little., because else you have a very strange pan)

Girl 1: But it does not have to look attractive at any price.

Ad 5. They look for a hierarchy in the goals

In both groups the pupils understand that there are goals they are striving for and others not:

What are we going to make and what are we not going to do? (Team 2)

The teams discuss the relative importance of the goals and the right order to test these goals.

"And this one, <u>does it fit in with the assortment</u>? is not needed at all costs" (Team 1)

Or, look at this exchange:

Boy 1: I already know it (what to choose), this one to check if it is strong enough,

Boy 2: No, that is not our main goal. Actually, ..

Boy 1: Of course it is, because when it is feeble ....

Boy 2: No! This one! (puts goal card is it attractive down)

Why? When it is not attractive, why will people buy it? And after that, comes strong enough.

Boy 1: But it should be first strong enough. Do you know why? If it is feeble, you will fall through (the chair)

Boy 2: When it is not strong, it is also not attractive. Do you get that?

Boy 1: Yes, but you should first..   (Team 2)

When the teacher tells to wrap up, both teams make a final decision. Team 1 selects "Do the parts fit together" and specifies this as "How can we slide the lower part of the pan?". Consensus is not reached in team 2. Their discussion is unfinished and they disagree about the hierarchy of the goals. The goal written down (is it strong) is not supported by all team members.

Table 3 shows the goals from the six design teams. It shows that most teams decide to focus on goals related to technical feasibility. Team 4 focuses on social desirability. They choose to focus on something uncertain in their design idea that they view as important for their target group: *But will this hold well? It is for people with rheumatics.*

What can we conclude about selecting testing goals? The pupils in the two teams are consciously discussing and selecting goals relevant for their design idea. With the prototype discussion game as a basis, they are able to develop and apply sound and practical reasoning strategies towards prototype goals that are relevant.

The pupils understand that it is impossible to go for all goals at the same time and understand that adequate testing goals are related to something important that you are not sure about how to design it exactly or do not know how the idea will work in practice. They also reason from materials towards the goals and notice that some goals are not possible with the planned materials.

Although nor the teacher nor the researcher had asked the design teams to specify their question, all teams, except team 2, had developed a very specific question to pursuit at this point, see Table 3. They are able to narrow down their focus and to ask specific questions to their prototypes as successful professional designers do.

The dialogues also show that it is not an easy job to find out on which goal to focus on to forward the design idea. The lack of consensus in the book chair team is not only due to a lack of time, but also because it is a complex process to understand which goals to discard and which ones to use in prototyping.

Table 3: Goals selected by the teams

T	Problem and initial design idea	Goal in prototyping on the worksheet	Specification by the team
1	Pan to cook and cut potatoes in once	Do the parts fit together?	How can we slide the lower part of the pan?
2	Chair with support for book	Is it strong enough and safe to use?	Not explicated.
3	Device to open jars	Is it strong enough?	Is the part used to open the jar strong enough?
4	Special scissors, powered by a rope	Is it pleasant to hold it?	Is it pleasant to hold the scissors?
5	Automatic potato peel machine	Does it work?	Can the knifes peel the potato automatically?
6	Potato peel machine based on a drill	Does it work?	Can we peel a potato with a drill?

4.4 Behaviour during prototyping

This paragraph describes how the selected prototyping goals were utilised during the prototyping process. Do the pupils refer to these goals, follow them and do the goals play a role when they make decisions about what to make? The behaviour of team 1 who had a specific, shared goal to focus on and team 2 who made a prototype without a specific testing goal will be described and compared.

Team 1: Moveable bottom Potato pan

Team 1 works on a potato pan that can be used to both cut potatoes and cook them. They selected the goal card "How do the parts together and specified there central question as "How can we make the lower part of the pan slide".

Two minutes after starting to build, this conversation takes place between the girls.

Girl: Look, you can just cut this off.

Girl: No, here! Because we are not going to make a working pan, isn't it?

Girl: And how about the bottom at the bottom?

Girl 1: yes, you can cut this. Yes, but look. This can become the bottom at the bottom because this has the same measurement as the side has

Girl: That is really handy. A handy box because it has already the right measurements.

Girl: But how to do it?

Girl: We cut it loose here and then we take a look. No, we cut it here loose.

Girl 1: but the bottom at the bottom needs to slide out of it.

Figure 5. Prototype team 1: pan to cook and cut potatoes

We could not always identify who was speaking, but it is clear from the data that at least one girl or maybe two girls continuously remind the whole team during this episode that they have to make a moveable bottom. This does not only happen in the above episode but throughout the building process, and say things as

" *But this "bottom at the bottom" should be pulled out"*

"*But this "bottom at the bottom" then?"*

"*Yes, but when we want the "bottom of the bottom" to go into it, then we should fix this completely together".*

The team invents a word to describe the specific part that has to be moved, in Dutch "onderbodem" or dubbele bodem" that we translated with "bottom at the bottom" and "double bottom", see figure 5 for a picture of the prototype.

They use the specific goal to explain to each other what they are after. A very clear example is an episode that takes place after fifty minutes of building. At this point one of the girls indicates that she doesn't understand what they are doing. A few minutes the later the following dialogue takes place:

Girl: Do we need these things?

Girl: Yes, for the double bottom and for the knives.

Girl: But for this bottom, we really need to check it out, because I don't know yet…. .

Girl: Now, I do know that as you can lay it in the following way. The bottom is the bottom. And then with this kind of little things.

Girl: The bottom should be moveable. I know a little how we can do it.

Girl: Me too. With a big crack. .

Here, we see that the specific testing goal is helpful in explaining to each other what they are doing. On the video we see that they keep on tinkering collectively to make a moveable, sliding bottom.

The team as a whole is very much focused on achieving this specific goal. The girls were also able to tell each other at times that some goals are not important.

Girl 1: "What we are going to make now doesn't have to have to be life-size. It makes no difference that our pan is not yet very big, because …you won't be able to cook potatoes for a whole family in it, but yes….

Girl 2: But grandmother Tina is on her own, I assume that she won't eat more than three potatoes.

The team appears to be in a flow and is cooperating. The recorded dialogues show that team 1 is all the time focusing on building the sliding mechanism. They keep on relating what they are building and the decisions that they make to the goal of a moveable bottom. This team benefited in their prototyping activity from the clear, specific, shared building and test goal. The result was a prototype that showed the moving mechanism.

Team 2: book chair

The process in team two was quite different. These pupils wanted to build a chair that supports people with rheumatics when they read heavy books. Their key idea is that the book is supported by the elbow-rests of the chair.

As described before, this team did not agree on which prototyping goal to select and was the only team who did not formulate a specific goal in terms of their own prototype. Some team members

wanted to check if the prototype was strong and safe enough, but others did not agree and had other preferences such as is the chair attractive.

During the prototype process none of these goals are mentioned explicitly. They describe and discuss what they are doing in terms of materials, e.g. "Shall we cut one or two flaps?". However, they do ask each other about why they need certain elements and materials, e.g. one of the boys asks "Why do we need a U?" and another one answers: "To sit in".

Figure 6. Prototype team 2: "Book couch"

The cooperation in this team is not at all times smooth. Not all the pupils are always actively involved in the construction process, especially one pupil does not know what to do and hangs around. In the post-interview the team member evaluates their prototype as follows. "I think that when you proceed to make this, it would be a good idea".

What can we conclude about team 2 and what is different compared to team 1? The team does focus on a central concept from their design idea and builds a chair with elbow rests. They do not relate what they are making to a specific testing goal and have less clearly in mind what they want to discover through the prototyping. Their decisions are not backed up by a collectively shared testing goal and this might be the reason why one pupil does not know how to join the making process.

4   CONCLUSIONS

A specified testing goal will function as a shared anchor during making. A shared testing goal enables a design team to tune decisions about what to make and how to make towards the testing goal. It also supports pupils in realizing that other goals can be ignored, not because they are not relevant for the final design, but because they are not relevant at this point in time. A game like the developed prototype-discussion game is a good way to actively involve pupils in relating goals to prototypes. They enjoy to look at

pictures and selecting matching goals they become acquainted in a playful with a large variety of testing goals and various prototypes examples.

Although the game functioned well in becoming acquainted with testing goals and prototypes, a redesign of the game is needed. First, pupils need more explanation on how to form a prototype-goal pair. A few examples of good "pairs" or a demonstration by the teacher is needed. During When this demonstration is done with an ugly prototype that has great testing qualities, the misunderstanding that the prototype is meant to test good looks is directly tackled. Furthermore, the use of questions to describe test goals caused confusion. A new wording such as "To test - does it work?" might be needed as well.

Second, the game did not stimulate pupils enough to exchange arguments for selecting goals. Research on this is needed. Collective selection of one goal card as intended might solve the problem or a more radical change in the playing mechanism.

The prototyping discussion game was a well stepping stone towards goal selection for the own prototyping. The insights from the game were easily transferred to the own prototyping process. The pupils that we observed were able to develop and share sound heuristics for selecting prototypes without any help of a teacher. Five different strategies were observed:

When these strategies are collected, explicated and shared in a whole class activity, for example by introducing a moment of collective reflection half-way during the selecting process, pupils will learn even more about purposeful prototyping.

Five of the six design teams were able to select a goal card and formulate a specific design question. Selecting a prototyping goal is however a complex process and at times pupils may need teacher support. It seems crucial that pupils use very specific testing goals and understand that they may ignore other goals.

Making and testing is essential in learning design and technology as it enables children to reflect-in-action and learn from real-world phenomena. Fablabs and maker spaces provide new opportunities and prototypes related to these opportunities can be included in the game. More research on the types of prototypes that can be made in primary school contexts may support the selection of prototype pictures in the game. This would support the selection process of goals and increase pupils knowledge about the kind of materials that they can use in their context. In other studies on making and prototyping in primary school, the testing goal is given by the teacher (McFadden e.a. 2017; Looijenga 2015). This also increases intentionality and such a project

prepares for design projects with student-selected testing goals. Also at university level, engineering students use goals set by their tutors, e.g. first design for feasibility and then for usability (Menold e.a. 2017).

Our findings show that pupils at a much lower age can learn to develop their own prototyping goals to engage in purposeful prototyping.

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REFERENCES

Baaki, J., Tracey, M.W. & Hutchinson, A. Give us something to react to and make it rich: designers reflecting-in-action with external representations, Int J Technol Des Educ (2017) 27: 667. https://doi.org/10.1007/s10798-016-9371-2

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. In ; J .Walter-Herrmann and C. Bűching (Eds), FabLabs: Of machines, makers and inventors, 4, 1-21.

Boon, M., & Knuuttila, T. (2009). Models as epistemic tools in engineering sciences. In A. Meijers (Ed.), Philosophy of technology and engineering sciences (pp. 693–726). Oxford: Elsevier.

Camburn, B., Dunlap, B., Gurjar, T., Hamon, C., Green, M., Jensen, D., ., & Wood, K. (2015). A systematic method for design prototyping. Journal of Mechanical Design, Transactions of the ASME, 137(8).

Deininger, M., Daly, S. R., Sienko, K. H., & Lee, J. C. (2017). Novice designers' use of prototypes in engineering design. Design studies, 51, 25-65.

France, B., Compton, V.J. & Gilbert, J.K., Understanding modelling in technology and science: the potential of stories from the field, Int J Technol Des Educ (2011) 21: 381.

International Technology Education Association, & Technology for All American Project. (2007). Standards for technological literacy: Contents for the study of technology. Reston: International Technology Education Association.
Kangas, K., Seitamaa-Hakkarainen, P. & Hakkarainen, K. Design expert's participation in elementary students' collaborative design process,

Int J Technol Des Educ (2013) 23: 161.

Kelley, T.R. & Sung, E, Sketching by design: teaching sketching to young learners,. Int J Technol Des Educ (2017) 27: 363.

Looijenga, A., Klapwijk, R., & de Vries, M. J. (2015). The effect of iteration on the design performance of primary school children. International journal of technology and design education, 25(1), 1-23.

Looijenga, A. R. Klapwijk, M. de Vries (2018). Attention and Action during the Design and Technology lesson: by fine-tuning task characteristics, 36th International PATT Conference, Athlone, Ireland, 18-21 June 2018, pp. 278-287.

McFadden, J. & Roehrig, G., Engineering design in the elementary science classroom: supporting student discourse during an engineering design challenge, Int J Technol Des Educ (2018).

Meijers, A. W., & Kroes, P. A. (2000). The relational ontology of technical artifacts. Research in philosophy and technology, 20, Amsterdam, JAI, Elsevier Science, 81-96.

Menold, J., Jablokow, K. W., Simpson, T. W., & Waterman, E. A. (2016, June). The Prototype for X (PFX) framework: Assessing its impact on students' prototyping awareness. In ASEE Annual Conference and Exposition, Conference Proceedings (Vol. 2016).

Menold, Jessica, Kathryn Jablokow, and Timothy Simpson. "Prototype for X (PFX): A holistic framework for structuring prototyping methods to support engineering design." *Design Studies* 50 (2017): 70-112.

Ministry of Education of New Zealand. (2007). *The New Zealand Curriculum*. New Zealand: Wellington.

Ministry of Education of New Zealand. (2010). *Technology curriculum support*. New Zealand: Wellington.

Nia, M.G. & de Vries, M.J., Models as artefacts of a dual nature: a philosophical contribution to teaching about models designed and used in engineering practice, Int J Technol Des Educ (2017) 27: 627. https://doi.org/10.1007/s10798-016-9364-1

Parker, W. S. (2011). Scientific models and adequacy-for-purpose. *Modern Schoolman: A Quarterly Journal of Philosophy, 87*(3–4), 285–

293.

Schut, A. , Klapwijk R. and M. Gielen, Effects of Convergent and Divergent Feedback on Creative Thinking During Children's Design Processes, PATT, 36th International PATT Conference, Athlone, Ireland, 18-21 June 201, pp 506-512.

Sennett, R. (2009). The craftsman. London, England: Penguin Random House.

Van der Lugt, R. (2005). How sketching can affect the idea generation process in design group meetings. Design studies, 26(2), 101-122.

Wall, M. B., Ulrich, K. T., & Flowers, W. C. (1992). Evaluating prototyping technologies for product design. Research in Engineering Design, 3(3), 163-177.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. Cognition and instruction, 16(1), 3-118.

Wiliam, D. (2011). Embedded formative assessment. Solution Tree Press.

APPENDIX 1:
Design requirements for the game

Each pupil is actively involved in relating prototypes to testing goals.

Pupils learn from their peers through dialogue.

Pupils experience various prototypes. The prototypes differ with respect to the pursued goals and used media. The products that are represented are familiar to the students, but contain also new, unknown elements.

The pupils will learn about prototyping goals related technical feasibility and social desirability. Economic viability is considered less relevant in primary classrooms.

The testing goals are applicable to a range of artefacts so they are relevant for a range of design projects. However they also need to be tangible.

Pupils gain sufficient insight to select specific testing goals for their own prototyping process.

The game is fun to play and takes less than half an hour.

Teachers that are not yet experienced in design education are able to guide the learning process.

Colophon

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