**Cooperation between primary schools and technological companies: a matter of boundary crossing**

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**Abstract**

In this paper, three cases of cooperation between primary schools and technological companies are investigated from the perspective of the learning mechanisms of boundary crossing: do stakeholders learn to *identify, coordinate, reflect on* and *transform their primary processes?* We focus on authentic technological processes versus (mere) exposure to explanations or instruction, and on the development of 21st century skills. In case 1 primary school teachers were trained by experts on 3D-print technology. Both parties worked together on educational design, resulting in weekly lesson series for half a year. Case 2 describes the process of participation of teachers and students with respect to robotics and 3D-printing in order to design and create attractions for a theme park called 'WitchWorld'. In case 3, students from a teacher training college were trained by field experts on 3D-printing and on new technologies related to water management. Students designed lessons to familiarize pupils and in-service teachers with these technologies. In all three cases we focused on the development of skills and attitudes for science and technology in connection with other educational objectives of primary schools. We describe and analyse the successes and pitfalls for these forms of cooperation.

**Keywords**: boundary crossing, primary education, design based learning

## INTRODUCTION

In the Netherlands the number of technology graduates is disappointing. The gap between education and technological practice is partly due to the fact that primary schools do not have a clear perception of what technology really is and why technology is important for children (Dutch Technology Pact, 2015). This knowledge can in theory be acquired from technological companies. The question is, how?

Schools and companies have their own different language, goals, procedures and habits. Sustainable cooperation requires that both transcend their comfort zone and learn to participate in each other's working processes. This can be seen as a process of boundary crossing (Engeström, 2001). Elaborating on this concept, Akkerman and Bakker (2011) discerned four mechanisms which can stimulate learning in boundary crossing processes: ***identification, coordination***, ***reflection*** and ***transformation***. The process of ***identification*** enables the parties concerned to identify similarities and differences between their organizations. This will lead to renewed insights. To allow effective ***coordination*** between practices, collaborators have to put effort in new or existing resources and procedures, like agreements or rubrics. Such resources and procedures are called 'boundary objects' when they preserve their inherent function in varying practices. ***Reflection*** may occur when cooperating parties become aware of differences in perspectives on both sides. This can be a process of perspective making (user awareness of own perspective) and perspective taking (learning to appreciate). ***Transformation*** comes into view when parties change their practices or create new ones.

## DEFINITION OF PROBLEM

This paper reports on three recent experiences in boundary crossing between primary education and professional technological practice. We aim to contribute to the development of a theory for technology education that has impact on primary teachers and students alike with respect to their attitudes and skills for technology and design, to 21$^{st}$ century skills and to other important objectives of the primary curriculum. We investigate the nature and extent to which students, teachers and pupils explore or participate in authentic technological processes (e.g. manufacturing, designing, testing) and develop 21$^{st}$ century skills such as problem solving, critical thinking and creativity, and how this is influenced by various forms of cooperation with technological professionals.

## METHODS

We explore three cases of boundary crossing. In the first case, teachers receive training from experts on 3D-printing and we focus on the success of implementing this technology in their regular classes. In the second case, primary school students participate in the working processes of a company that designs objects for an amusement park using robotics technology and we focus on what teachers learn from observing and analyzing these activities. In the third case, student teachers are trained by experts on 3D-printing and on water management, and we focus on the effect of this approach on professional development of the schools.

In all cases, we collected qualitative data through frequent observations, interviews, reflective and evaluative dialogues, and analysis of student reports and products.

## CASE 1: 3D-PRINTING AT SCHOOL

This pilot was initiated by the municipality of Almere and the company FabLab Flevoland and executed at two primary schools (called Het Palet and Digitalis*)* with an interest in digital learning and 21st century skills.

Six teachers were trained by FabLab instructors to build their own 3D-printer and to use 3D-modelling software (SketchUp). They designed two lesson series of twenty weeks, one for students aged 6 to 8 years and one for 10 to 12 year olds. The lessons for the youngest were on basic tools and application for electronics, programming, and 3D-printing (e.g. Makey Makey, BeeBot, Blokify). For the eldest, lessons aimed at enabling students to use SketchUp to design and print objects (e.g., doors, windows) to be implemented in cardboard houses. Throughout the pilot, teachers altered initial designs when tasks were too difficult for students to do in the planned way and time, when prerequisites were not in order (e.g., break down of the 3D-printer or internet access) and when FabLab-support to help with hardware en software problems was unavailable.

3D-printing attracts a lot of media attention, and is supposed to be a phenomenal appetizer for schools. All the pupils and teachers in this pilot were indeed fascinated by the printer and its manifestations. They were proud to have it in their school and felt privileged as participants in the pilot. In both groups, all students were very involved and devoted much more time on science and technology than usual. Students and teachers agreed that it improved affinity with modern technology. With respect to 21st century skills and other goals: teachers noted improvement in cooperation and both teachers and pupils remarked that mathematics made much more sense in this context.

However, as the lessons consisted mainly of instructions (age 6-8) and skills training (age 10-12), little attention was paid to open-ended problem solving, creativity or critical thinking. The FabLab instructors insisted on the importance of skills training: ‘The only way really to develop the needed skills, it is just hard work’. Teachers depended on their professional expertise and felt uncertain to leave things more open.

Throughout this pilot, FabLab professionals and teachers reflected on the process. Teachers began to make some changes by themselves as they had doubts about the suitability of the software tools and pedagogical approach. By contrast, FabLab employees did not change perspectives but guarded the ‘best approach’ according to their expert thinking. The 3D-printer, as a boundary object, coordinated activities and induced a certain amount of reflection, but transformation of practices still proved difficult. The school remained unable to independently produce solutions to technological problems using 3D-printing. The company still found it difficult to view their efforts as contributing to the development of cooperation skills or mathematics objectives rather than as learning others to use a 3D-printer.

Our conjecture is that it might be better to introduce children into new technologies, like 3D-printing, in contexts where this technology is really useful: in a real work place. This is investigated in the next case.

## CASE 2: DESIGNING AMUSEMENTPARK ATTRACTIONS

In this pilot, Witchworld, a creative company developing a new amusement park for the city of Almere, cooperated with two primary schools. Witchworld designs flying witches, medieval princes and princesses, trolls, and the like, and uses various new technologies such as robotics and 3D-printing.

WitchWorld already cooperates with schools for (higher) vocational training in providing learning experiences and likes to expand their reach to primary schools. Two teachers and twelve students aged 9 to 12 year were involved. WitchWorld supplied two professionals (including the company director) to elaborate the educational design and interact with the students. Lessons were executed partly at WitchWorld and partly at the schools and involved creative thinking to solve meaningful problems. The aim of the pilot was to help the regular primary school teachers to discover their students' talents by observing them during technological problem solving.

Students should receive time and space for fantasies to emerge freely and to express them. This was achieved through tours and conversations in the WitchWorld workshop; initially as inspiration and subsequently to improve the (robotic) products that were designed and made in collaboration with WitchWorld technicians. This developed, from designs drawn on paper, and from unlimited fantasy to more technical precision. Designs were converted by technicians into 3D-prints and finished off by the students by colorful painting. The focus was on learning to construct a very simple real robot, able to make movements, by assembling the electronics and other necessary devices in a frame. Furthermore, there was room to advise WitchWorld in the production of attractions for the theme park with drawings of your own ideas for an attraction.

Pupils and teachers alike were fascinated by the WitchWorld surroundings with fairy tale objects and robots everywhere. Pupils were deeply involved in all activities, even though they were often bewildered by the appeal to their fantasy, and even though the tasks were often difficult to grasp. They felt privileged to be part of this project and would love it to be continued. In this sense, identification took place. As to teachers, they felt confirmed that this kind of collaboration can be an improvement for the school curriculum. However, the creative intentions (divergent imagination leading to the production of an object of your own design, and assisting WitchWorld in production of attractions) were only marginally realized.

The joint reflective sessions in this case were too short and too few to express and analyze reflections on the many levels involved. So, some interesting questions on the brink of coordination and transformation, were now only hinted at. For example, all considered the pedagogical approach to be mainly instruction driven, even with respect to fantasize on something. The WitchWorld director commented on this as necessary to accomplish results in a short time, and as characteristic for a production company. These expressions about identity are a good start for further reflection on the complementary roles of teachers and technological professionals, but too few to conclude that transformation is on its way.

**CASE 3: COMBINING PROFESSIONAL DEVELOPMENT WITH PRE-SERVICE TRAINING**

To bridge the gap between primary education and professional practice, fifteen third year students of Windesheim teacher training college, having a science and technology profile, were trained by field experts in seven workshops based on two subjects: water management and 3D-printing. Workshops were based on learning by doing and given either at Windesheim or on location. Time was invested to provide students this opportunity. In four of the workshops, students visited the external parties involved, being in the environment of expertise. Experts from *Wetsus* (European Centre of excellence for sustainable water technology), *the faculty of Geoscience* (Utrecht University)*, RWZI Zwolle (sewage treatment), LAB21* (Windesheim innovation Centre for ICT in didactics and support) and *Windesheim* (teachers Science & Technology, Mechanical Engineering and researcher) all had one mission: interest young children for science and technology. In this case, students were trained in knowledge, attitude, didactics of research and design and development of 21st century skills in order to design lessons to familiarize pupils and in-service teachers with these technologies.

According to students, the schools they visited ‚didn't make time for science and technology or still use methods (reading a text and answer questions). They all were very disappointed as the related schools all signed an agreement on future learning (coordination). Even schools who profiled themselves as science and technology schools were not familiar with the didactics of research and design. This identification can be seen as othering. Some students were more lucky because their schools were a step ahead

Lessons designed varied from isolated topics not related to the given workshops (e.g. float and sink) to lesson series which were meaningful, challenging and stimulated curiosity. Almost all students mentioned the concepts of research and design in the lessons designed and five of them described all steps separately. A lot more focused on 21$^{st}$ century skills (cooperation, critical thinking and communication were mentioned the most). Half of the students incorporated new technologies from the workshops in their lessons, some organized either an excursion or a guest speaker. The lessons designed prepared the ground for education in more than one subject, also language, math, art and others were incorporated.

From observations students concluded that children were not motivated in case technology lessons consisted of reading a text and answering questions. In case these lessons included new technologies like 3D-printing or related to water management, where children were able to learn by doing, making mistakes, cooperate with each other, they were motivated, asked questions, absorbed information and were very enthusiastic “When do we get another lesson in science and technology?” Some even continued to design at home. This made the students but also the in-service teachers even more enthusiastic. Students also remarked that this way of learning has a lot of advantages because more subjects can be related to it like language, math, art etcetera. On the other hand, some students indicated that children are not used to work according to didactics of research and design and needed more explanation, asked for confirmation or behaved restless. Students are aware of steps to take in research and design, this was also an explicit focus in one of the workshops. However, only five students explained the steps in their lessons designed, to make children aware.

Students experienced the workshops as very valuable and were surprised about the many different perspectives of water management. Reactions on 3D-printing varied from new and anxious to fantastic and unique experience. All except one, considered 3D-printing as useful because of the possibilities in real life, like printing an Adidas shoe from recycled plastics found in the ocean. Most of them considered 3D-printing in primary school to be an added value for development of 21$^{st}$ century skills (*e.g.* creative thinking and cooperation) and to create a positive image of technology. At the same time, they also mentioned problems/disadvantages such as the poor quality of the printed products, price of a 3D-printer, time and energy needed for printing and teachers/students who are not ready for it yet. In the end, two students still felt insecure, because of lack of knowledge about new technologies.

When reflecting, students all agree that there must be room for children to explore, ask questions, do research. According to them, didactics of research and design should be implemented in the curriculum, some even want this to start from first grade in order to create a positive image of science and technology. All students except for one were given the necessary leeway to design and teach their lessons (legitimating coexistence in identification). The one who couldn’t, designed lessons according to what was learned in the workshops, in order to pass the exam, however during internship the student adapted the method lessons to make it more challenging.

Preparation time for the profile was limited to ten hours and according to the teacher by no means enough. The added time was worth it according to reactions of students (I learned a lot, I am aware of science and technology in daily life, it makes me enthusiastic and I’m willing to learn more), children (I want this more often, you can do it yourself) and teachers (Fantastic lessons, we get new insights). Despite their enthusiasm, only two students dared to arrange learning situations outside the classroom, using the external parties involved. Two others invited experts into the classroom.

**CONCLUSION:**

In all three cases, boundary interaction between educational institutes and external parties, resulted in enthusiasm amongst pupils, students and teachers. New education material was developed and new technologies were introduced. By touching different (modern) technology applications, a positive ***identification*** started up. However, the things learned were not automatically translated into education materials, didactics and products of desired quality.

In all three cases, cooperation between the parties involved started from a collective mission statement towards technology education, but was limited to (practical) ***coordination***, particularly in case of creating a balance in scheduling and facilitating essential practical conditions to achieve goals.

In order to be able to ***identify*** key elements of the different practices, and understand the importance for life, themselves and others, it is important for pupils, students, teachers to experience 'real technology' practices. In most of the cases preparation of learning activities was done by external parties, mostly organizations having their own educational department (University, institute, company).The way of learning differed in each case.

Case 1

External experts from one organization taught teachers how to work with one specific technique (3D-printing). Together, they developed lesson series for primary school pupils. In both situations new technology had the focus of attention, there was no focus on the didactics of research and design. The external party facilitated the teacher in the role of troubleshooter for technical problems at school. After the pilot, both parties searched for alternatives to implement the didactics of research and design in their own context situations.

Case 2

Although pupils worked together with real technicians and designers on location, the research and design approach didn't come out in the way as expected. According to WitchWorld this was due to a missing road map (boundary object). In this context, coordination of both internal and external actors (role/task of schools) is essential.

Case 3:

Workshops, performed by educational teachers and external experts were focused on didactics of research and design and learning on location. All students were aware of the need to change education from isolated learning into didactics of research and design. Half of the students introduced new technologies into their lessons. It was obvious that only a few students really followed the steps of empirical science in their lessons designed and given to primary school pupils. Only four of them used the contacts to organize lessons on location or in school with other professionals.

In case we look at the role and reactions of those involved in educational organisations, the teacher in case 3 made a major contribution to the engagement of external parties, although the time needed had been disproportionate in relation to the time set. Normally, this is not part of a teacher's job. In case 2 reflection on engagement showed the need for extra manpower, a crucial aspect of ***coordination,*** which is equal to the competences ***to identify*** practices of schools and companies and link them. In case 1& 3, the teachers & students involved, combined 3D-printing with other subjects like math and geometry and concentrated on pupils collaboration (aspect of $21^{st}$ century skills) and implementation of didactics of research & design. In case 2 teachers and school principals stated to continue collaboration with external parties and to use the experiences to improve their own didactics and curriculum. In case 3 collaboration with one of the experts has been continued, this needs further research.

Boundary crossing has been elaborated partly but all parties involved reflected on improvement of their roles in process of collaboration which may serve as suggestions for clearer identification of their own field and distinguish from others. This will result in a complementary way of working. Even if ***transformation*** to further integration of learning practices seems to be useful, ***reflection*** on different values of current systems and borders is needed.

Further investigation is needed in the way schools/teachers implement science and technology in their curriculum with support from external parties, the educative role that fits practice and what boundary objects are needed.
In order to gain an insight into collaboration leading to both enthusiasm and stimulates a good quality of technology education, perseverance and fundamental investment in time and manpower in educational organisations is conditional.

**LITERATURE**

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