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 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.

Table 1: 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 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.

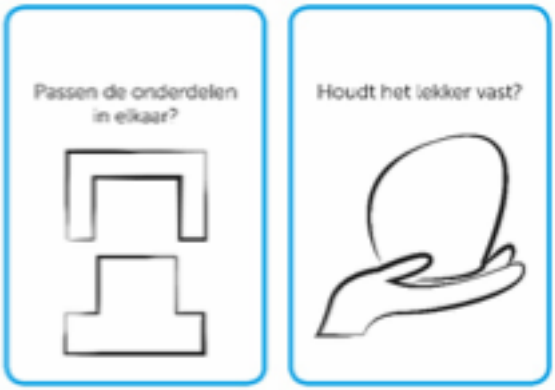

Figure 2. Example of goal cards " Do the parts fit together?" and "Does it hold comfortably"

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?".

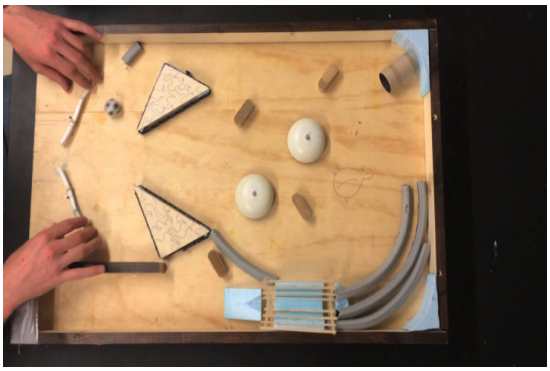

Figure 4. Pinball machine

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, does it fit in with the assortment? 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.

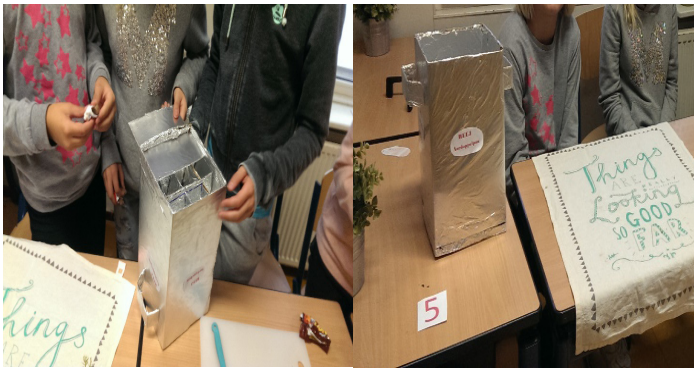

Figure 5. Prototype team 1: pan to cook and cut potatoes

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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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.