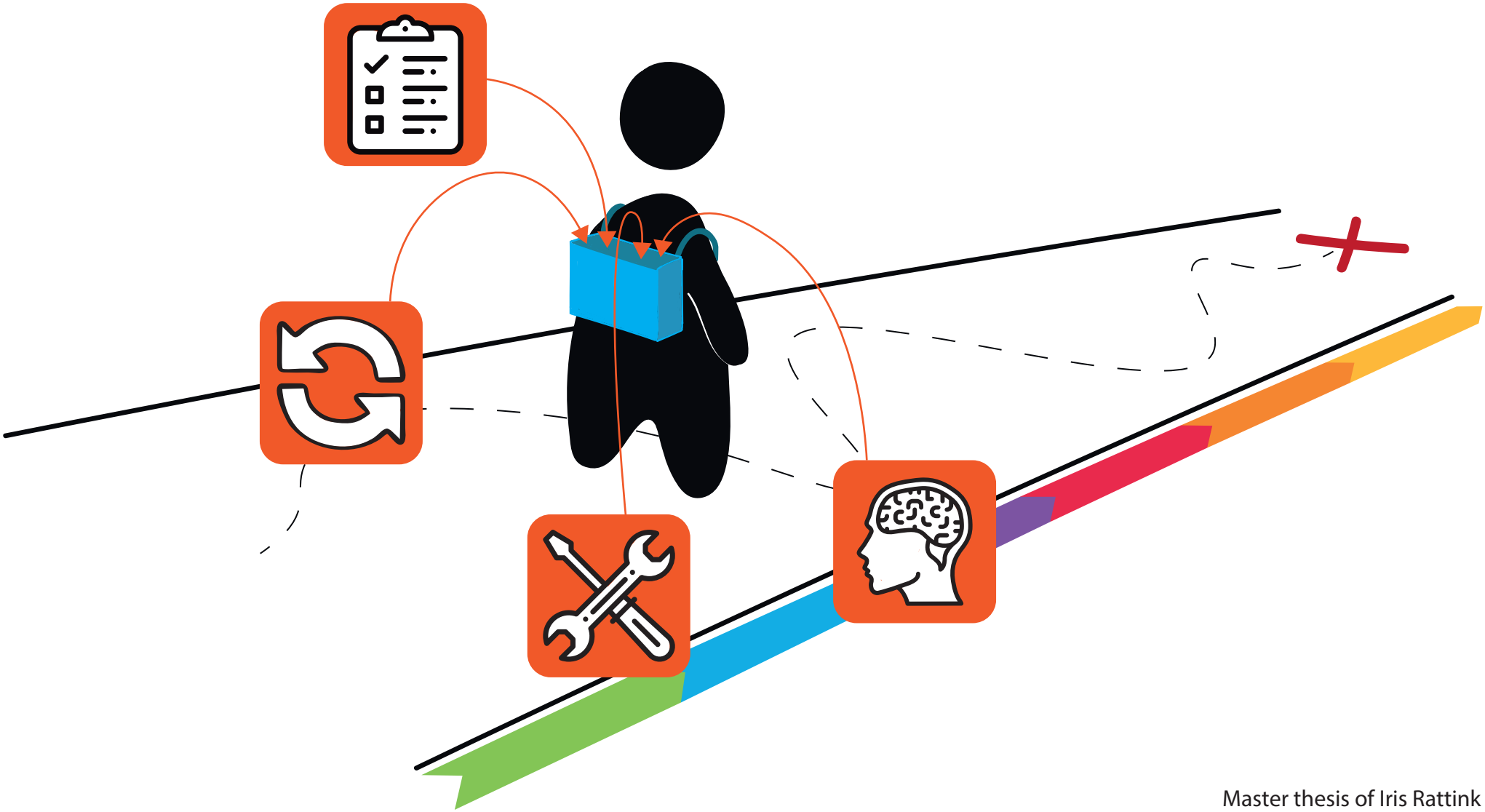
Meaningful prototyping in Primary Education



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Foreword

With this project I finish my master Design for Interaction. I could not have wished for a better project to end my studies with. In this project I had the chance to combine two passions, education and design. I would like to take the opportunity and thank, in no particular order, several people who have helped me during this project.

I would like to thank my supervisors Remke, Iemkje and Eva for all their input and feedback throughout the project. During the process I had to adjust my approach and work from home due to COVID-19. I have never experienced it as a big hinder because they all always helped me think of solutions and helped adjusting my project, allowing me to continue with it.
I also want to thank Eveline for kind of being an extra supervisor and always being open to help and think along.

I would like to thank Mathieu for pointing out this project, connecting me to Remke and involving me in the Lab Rats meetings. It has been very valuable to share experiences and tips with other students doing projects involving children. Also thanks to the other students in the Lab Rat meetings for sharing their experiences and brainstorming with me.

I would also like to thank Leon for his help in the beginning of my project. And also thanks to the students working in 'het afstudeerhok'. It was nice to work in the same room and being able to have serious conversations about our projects, and I especially loved the random break-conversations.

In my project I have been able to learn from stakeholders and users. I would like to thank everyone that I have interviewed at the start of my project and huge thanks to all the families, children and teachers who tested my designs at the end. Due to COVID-19 it was uncertain in what way I would be able to test the designs and they all made it possible to test and enabled a better outcome of my project.

I would also like to thank my friends from study for their input and support when I needed it, my friends from sports for playing ultimate with me so I could clear my mind and my friends from Vierkant for playing (online) boardgames with me.

Last, but not least, I would like to thank my family for all their support and help throughout my project. And Gerwin for always being there for me and making sure I am not too hard on myself.

I have really enjoyed the journey of the last project of my studies. Surprisingly, I have not experienced a lot of stress throughout the project. I think this is partly due to all the great support I have had. Again, thank you all so much!

Executive summary

At the moment design is taught in primary education. Teachers often use the design cycle which consists of six phases: 1) Exploring & formulating the problem, 2) Generating & selecting ideas, 3) Generating & selecting concepts, 4) Building prototypes, 5) Testing & optimising and 6) Presenting. There are several tools available for teachers to use when doing a design assignment in class. These tools are focused on exploring, ideating and presenting, but tools for prototyping are missing.

In a previous project Nadine Rodewijk developed a game, the Prototype-discussion-game, which was meant to help children in purposefully prototyping. This game is the starting point of this project and the goal of this project is to develop materials that are a contribution to the available tools for designing in primary education and make children use prototyping in a meaningful way.

Explorative research, interviews, observations and literature, show that children often do not have a goal when prototyping, while experts use prototyping to find things out. Designing is an iterative process and prototyping allows you to iterate. At the moment children often only make one prototype at the end of their process for communication purposes.

In this project three tools are (further) developed in order to stimulate the children to purposefully prototype and use prototyping to iterate in their design process. Due to COVID-19 all the tests in this project could not be performed in schools, since all schools were closed. Therefore, all the tools are tested at home.

One of the developed tools is the Skill tool. The goal of this tool is to teach children necessary skills for prototyping. When children do not know how to make things, they will not be able to make meaningful prototypes in a design assignment. Children get a step-by-step instruction in text and image which they have to follow. In the last step the children need to apply the skill they just learned in a different context. This way children already have practised applying the skill in a different context before they have to create a specific prototype in a design assignment.

Another tool is the Prototype-discussion-game of Nadine which is further developed. The goal of the game is to make children aware of the different goals prototypes can have. The Prototype-discussion-game is a card game in which groups of 3-4 children have to combine prototypes with goals. The children have five cards with different goals for prototypes on them and they need to combine one of the cards to a card with a prototype on it. The children need to give an argument for their choice and need to discuss which goal fits best with the prototype card.
The tests in this project show that the game makes children aware of the different goals and is experienced as a nice and educational game to play.

The last tool developed for children is the Iteration tool. The goal of this tool is to guide children through the necessary stages in order to iterate (see Figure 1). In order to iterate you first need to look forward and plan for the prototype you are about to make. Then you execute your plan and once it is finished, you look back and reflect on your progress and process. Lastly, you process your learnings and decide on what the next step would be before you enter the iteration model again by planning for your new prototype.
The tool consists of multiple worksheets which are related to the stages of the iteration model. The tests show that using the Iteration tool helps the children to prototype purposefully.

In this project there is also a tool developed for teachers. This Info booklet provides information about the role of prototyping in a design process. The booklet also provides examples and information about the tools developed in this project that can be used in class when prototyping. Teachers mentioned that this booklet is very informative and can be useful when preparing a design assignment.

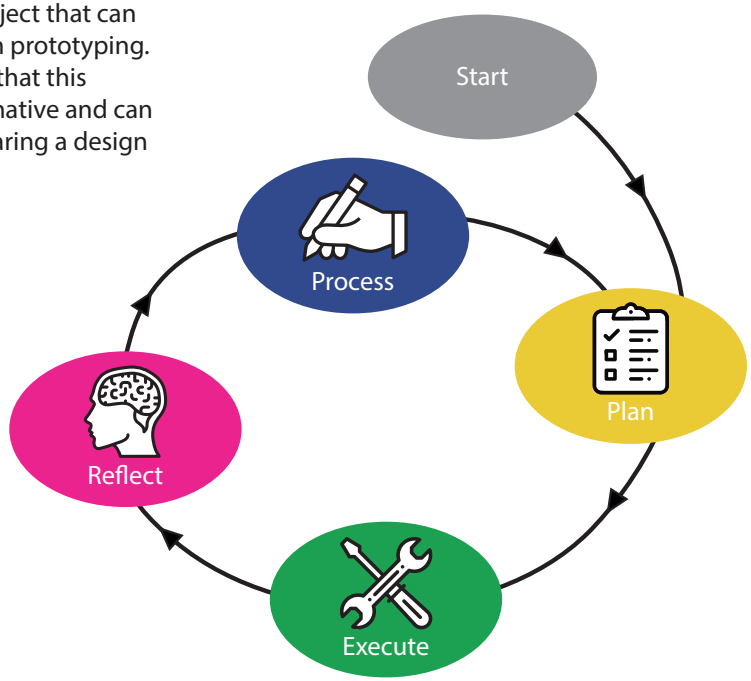

Figure 1. *Iteration model*

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1. Introduction

1.1 Context

This project contributes to the research of Science Hub TU Delft (Wetenschapsknooppunt TU Delft). The goal of this project is to let children make better use of prototyping in their design process.

The Prototype-discussiongame

In an earlier research by a now former student, Nadine Rodewijk, a game the 'Prototype-discussion-game' (Prototype-discussie-spel, see Figure 2) has been developed for the course 'Research of Education' (Onderzoek van Onderwijs, 6 ECTS) from Science Education & Communication. Appendix 2 shows the forms from the game developed by Nadine. The goal of this game is to get children to purposefully prototype their idea. This game seemed to trigger some good aspects to create the right mindset of the children (work purposefully), but it was not a one on one cause and effect. Science Hub TU Delft wants to further research the topic meaningful prototyping. They want to know if the game contributes to meaningful prototyping and if something else or more is needed to contribute to the process. This project has the game as a starting point and will research how to let children make better use of prototyping, in other words how to make children use prototyping meaningfully.

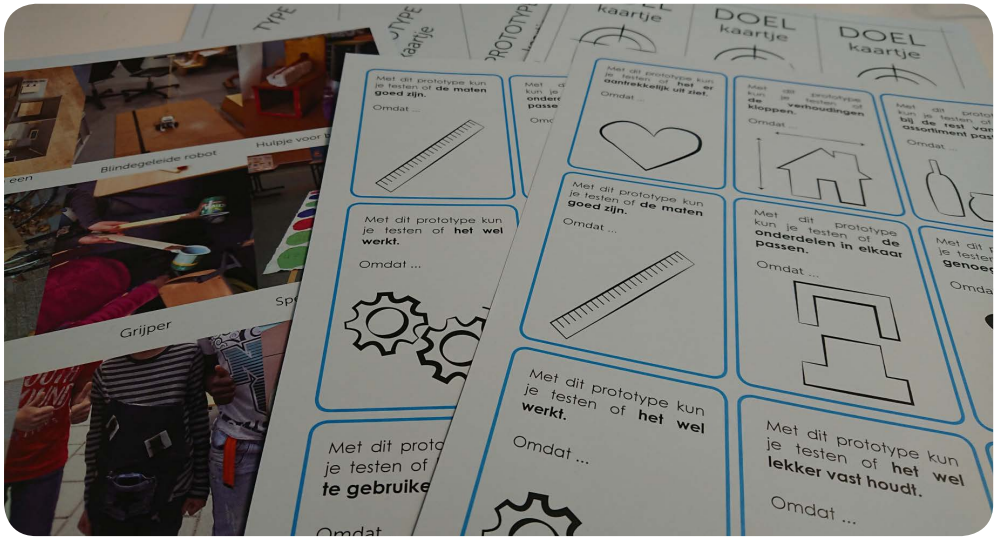


Figure 2. *Existing prototype discussion game*

Stakeholders

In this project several parties are important to take into account. Figure 3 shows an overview of the stakeholders involved in this project and the stakeholders for whom the results of this project could also be interesting. This project is aimed at the advanced stage of primary education, but can also be interesting for other levels of education, e.g. secondary schools and university, since prototyping is an essential tool in the product design process and often not fully used by novice designers (*Deininger, Daly, Sienko & Lee, 2017*).

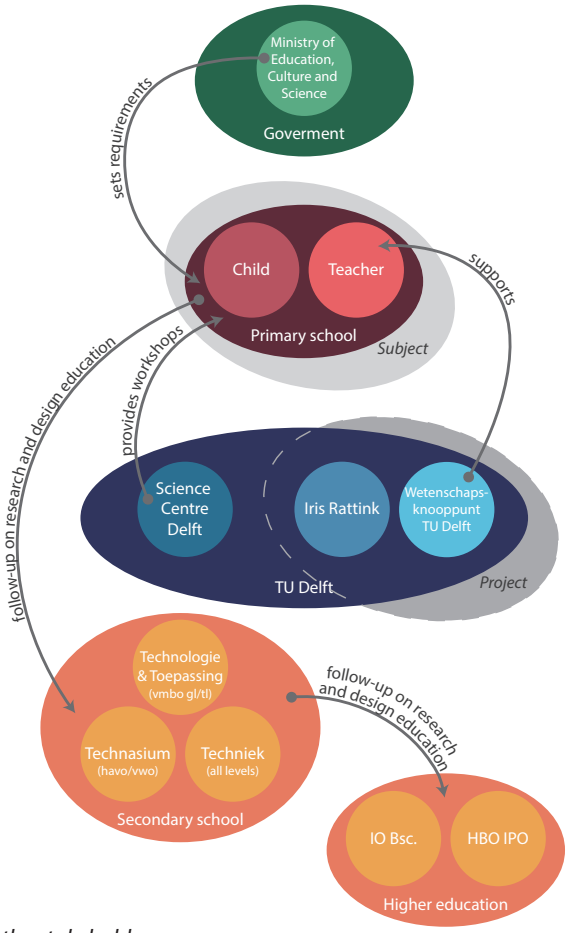


Figure 3. *Overview of the stakeholders*

Current role of designing in primary education

At the moment design is taught in primary schools. Primary school teachers often follow the design cycle (see Figure 4). This cycle consists of six phases and in the first three phases you first diverge and then converge.

From 2020 onwards schools are obligated to incorporate 'Science and Technology' (Wetenschap & Technologie) in their curriculum *(Deems, 2020)*. In this way children learn at a young age to design, research and use a problem solving approach. Figure 5 shows the components of Science and Technology in primary education, so by design and research assignments schools meet the requirements of incorporating Science and Technology in their education.
At the moment the curriculum of primary and secondary education is in process to be changed to contribute to the flow of going from primary school to secondary school to higher education, the coherence between subjects and a less overloaded programme. It should also allow teachers to use their own interpretation *(Curriculum.nu)*. In the proposal for 'Human & Nature' (Mens & Natuur) designing and prototyping are represented *(Leergebied Mens & Natuur, 2019)*. Before a new curriculum can be installed, the proposals first need to be translated to new educational goals.
For now the 'Ministry of Education, Culture and Science' (Ministerie van Onderwijs, Cultuur en Wetenschap) created 58 'attainment targets' (kerndoelen) for the primary education. Some of these attainment targets are aimed at design skills. Two of the attainment targets of 'Orientation on yourself and the world' (Oriëntatie op jezelf en de wereld) are directly connected to designing *(Ministerie van Onderwijs, Cultuur en Wetenschap, 2006)*.

Attainment target 44:
The children learn to create links between the function, shape and material use of products from their own environment.

Attainment target 45:
The children learn to design, create and evaluate solutions for technical problems.

SLO (Stichting Leerplan Ontwikkeling) has created TULE (Tussendoelen en Leerlijnen), a plan teachers can use in order to get the children to the attainment targets. This plan does not give clear instructions on how to teach a design process and how to guide the children through the process. In interviews teachers mentioned they have colleagues that use the TULE while developing their classes.

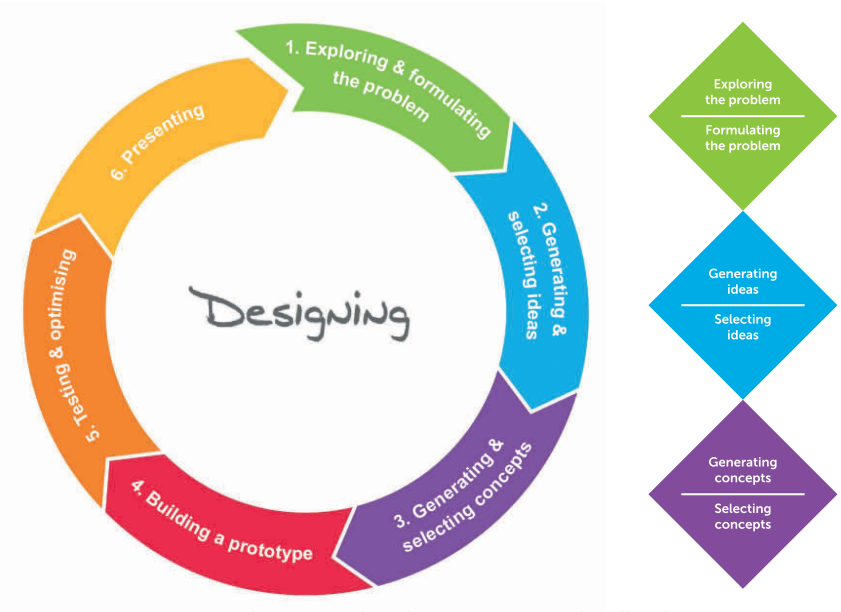


Figure 4. *Design cycle (Wetenschapsknooppunten Zuid-Holland)*

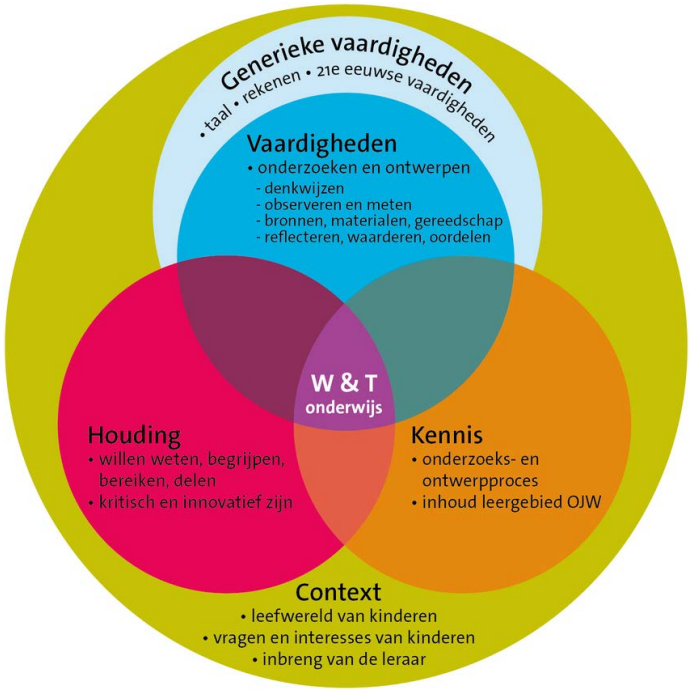


Figure 5. *Components of Science and Technology in primary education (SLO, 2019)*

Existing tools for design in primary education

In order to help teachers in educating children in design, there are already several tools available. The website of 'Your Turn' and 'Ontwerpen in de klas' provide materials for teachers and children to use in design projects.
Your Turn provides tools that support the children and train their (21st century) skills *(Your Turn)*. At the moment Your Turn has multiple tools for 'explore and define the problem', 'ideate', 'evaluate and select ideas' and 'present', but is missing tools for the prototype phase.
Ontwerpen in de klas has as goal to stimulate the creativity and problem-solving abilities of children *(Ontwerpen in de klas)*. The do-it-yourself section of Ontwerpen in de klas provides a few materials for the prototyping phase. They mainly provide explanations and suggestions for what a teacher and/or children could do and most of the time it does not include materials for children to use. The ready-to-go section of Ontwerpen in de klas provides design assignments of different lengths, including a planning and how to do it.

1.2 Assignment

The assignment for this project is to create a tool that is a contribution to the available materials and help for prototyping in primary education.

2. Research

In order to get a good understanding of the context, a thorough explorative research was conducted. By interviewing several stakeholders, a broad amount of knowledge is gained which can be used in this project. The stakeholders are experts in their field and the knowledge they already have is valuable for this project. Via observations of children prototyping, interesting and important aspects around the act of making a prototype are noticed. When observing, you gain other knowledge than you can get from teachers, since a designer looks at the process with a different background and notices different aspects than a teacher. And lastly, literature about design processes and prototyping is consulted. This way the existing knowledge from research about the context of this research is used.

2.1 Interviews

The interviews are partly conducted via the phone and partly in person. The persons interviewed are: three primary school teachers, three secondary school teachers, five Industrial Design teachers and three makers.
Primary school teachers have direct knowledge of working with children on design assignments and will provide meaningful insights into the current way of working. All three primary school teachers have experience with executing a design assignment with their students.
The secondary school teachers have knowledge of coaching secondary school students and go through the process of coaching students more often than primary school teachers. Two of the three secondary school teachers are O&O teacher. O&O is part of Technasium and stands for 'Research & Design' (Onderzoeken & Ontwerpen). The third secondary school teacher teaches 'Technical design' (Technisch ontwerpen), in which the students also go through a design process and use the design cycle. They can provide knowledge on what works and what does not work well when going through a design process.
The five Industrial Design teachers all have experience in coaching students in a design process, but do this in different types of courses. This will provide insights from different perspectives.
Lastly, all three makers have experience with design in primary schools and either sometimes coach these processes, or create materials related to making which are used in schools. They are aware of how design is implemented in schools and have their own view on making, they will provide insights that are more related to the actual making aspect in a design process.
The interview questions are about the following subjects: attainment targets, vision of interviewee, familiarity with the design process, external factors (background and parents), making prototypes, realisation of design classes, materials, own experiences, tips and tops.

Definition of prototype

During this research it became clear that the definition of what a prototype is and does, is not black-and-white. The word prototype has a different meaning for different people *(Berglund & Grimheden, 2011)*. Figure 6 (next page) shows the different definitions the interviewed groups gave.

Below you can find the definition of prototype used in this project *(Houde & Hill, 1997)*. This definition is chosen since it best represents the versatility of a prototype in roles and forms it can have.

> **A prototype is**
>
> *... any representation of a design idea, regardless of the medium.*

This means a prototype can have different forms. A model one use to explore or investigate, e.g. "Is this technical principle working?" is using a prototype. A prototype can be digital, 2D or 3D, as long as it is used to test or communicate something.

According to two of the five Industrial Design teachers a prototype is a model of an almost done design. For this project that definition is too restrictive. This project uses the term prototype as broad as Houde & Hill *(1997)* defined it.

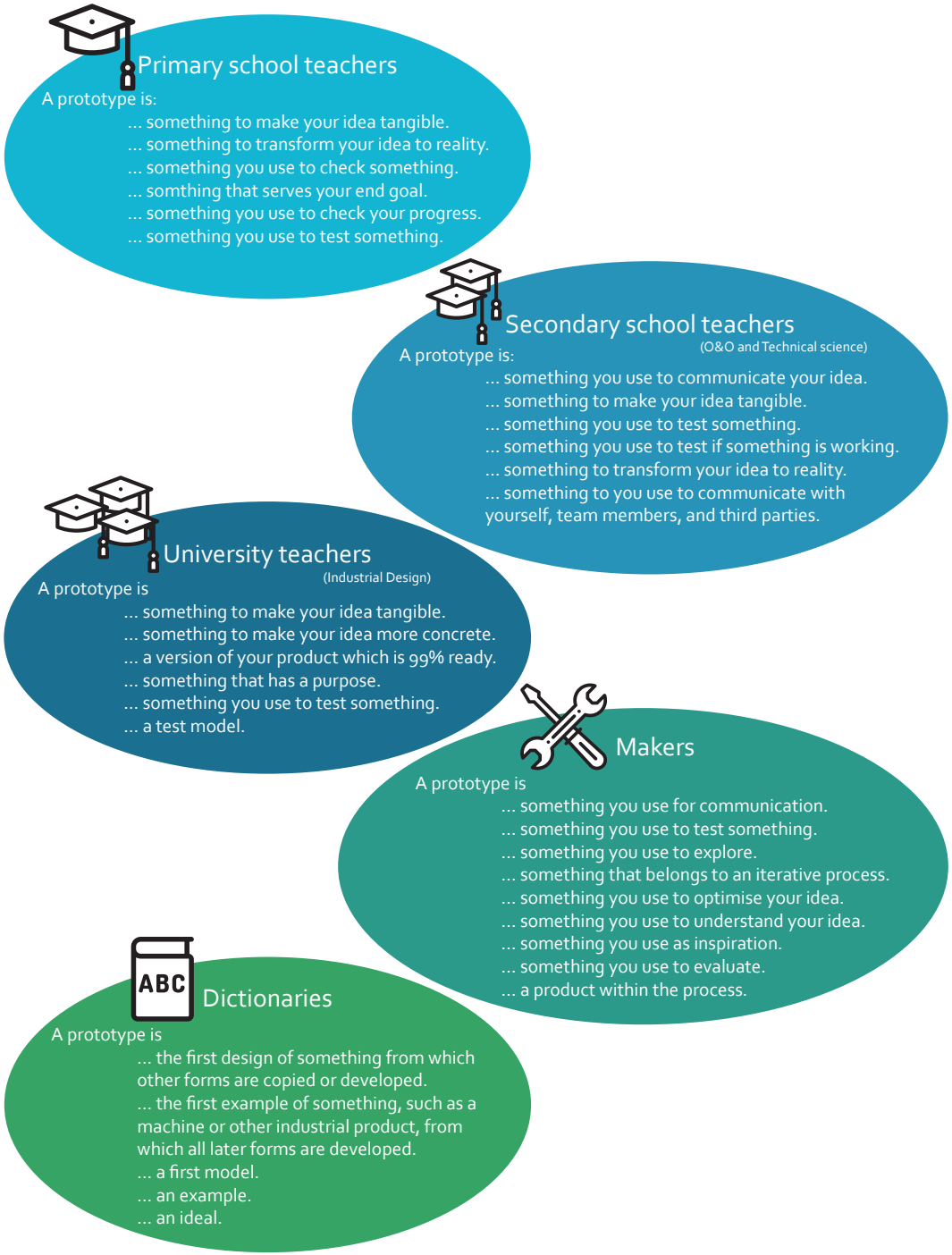


Figure 6. *Definitions of prototype per group*

Figure 6 shows that there is not a clear distinction between the different groups in how a prototype is defined. For example, in all the interviewed groups a prototype is seen as something you use to test or check something. An interesting difference between groups is that some Industrial Design teachers, as mentioned before, see a prototype as something that is 99% finished. What others would define as a prototype is in the eyes of theses teachers just a model and cannot be called a prototype.
Within all the definitions the interviewed groups give, there is a certain goal for which the prototype is used. This is in line with the believe that every prototype has its own goal *(Nieveen, 1999)*.

Design in primary education

As mentioned before, in 2020 Science & Technology is required to be part of the curriculum on primary schools. This means that design gets a bigger role and will be implemented more often in schools. In the interview the interviewees mentioned different reasons of why doing design assignments is so important. Both the primary and secondary school teachers mentioned that by designing you learn important skills which you can use the rest of your life. They mentioned soft skills and '21st century skills' (21e-eeuwse vaardigheden). Figure 7 shows the 21st century skills. From these skills the teachers mainly mentioned working together, problem-solving thinking, creative thinking and critical thinking. They also mentioned that children learn how to apply the knowledge they gained, and think it is a good challenge and preparation for the future, looking at education and jobs.
For the Industrial Design teachers doing design assignments seems a good way to challenge the children and to stimulate their creativity. Industrial Design students often need to learn to be creative again, because it gets lost in the way schools were set up. With design assignments you give the children the opportunity to be creative. For Industrial Design teachers it is also important that children understand design is an iterative process and not linear and that they should not be afraid of making things. You prototype to find something out, so finding out something does not work is still finding something out. One of the Industrial Design teachers also mentioned that everyone can design, as long as you follow (the right) methods.

Figure 7. *21st century skills (SLO, 2019)*

One of the secondary school teachers sometimes lets his students make multiple prototypes, to make sure all the members of the group have a task in making the prototype.

Necessary skills for prototyping

From the interviews with the primary school teachers it became clear that they do not spend much time on training making skills; skills that help you while making something, e.g. being able to work with tools and know how to use different materials. They do the usual arts activities and mention the children actually learn too little making skills. From the information gathered from the other groups, it seems as a big missed opportunity to help children in their capability of making. Both the Industrial Design teachers as the makers mentioned the importance of possessing making skills before you can apply them in a design process. Children need knowledge of materials and tools before they can see the possibilities. An Industrial Design teacher, with a pedagogical background as well, mentioned that children should be able to first explore without having obligations. The secondary school teachers mentioned that their students always possess the skills needed for a project, because before the project starts the students get small assignments to practise the needed skills.

Materials

All primary school teachers mentioned that they did not have a big budget for materials. They all mentioned the use of waste materials. Wood, cardboard and paper are also materials that are often used for prototyping in primary schools.
One of the makers mentioned the importance of the materials being cheap. In this way the teachers and children do not have to be afraid of wasting materials and can use them in any way they want. Another maker mentioned that tools itself are not dangerous. How you use a tool can be dangerous, so it is a matter of teaching the children the right way of using it.
One of the Industrial Design teachers mentioned she would advise to have basic materials and materials that can be used in multiple ways, such as rubber bands and paper clips.
Multiple interviewees also mentioned lego, electronics and duct tape as materials that are good to use for prototyping.

Facilitate a design process

Since almost all interviewees have experience in coaching others in a design process, they gave a lot tips on how to coach and what are important things to keep in mind in the process. Most tips are related to making, since this project is about prototyping.
In the preparation it is good to let the children make a plan of what they want to do, how and who will be in charge. To this plan also belongs a goal of what they want to achieve with their prototype. It also helps to let them make drawings of their ideas before they start prototyping.
When they start prototyping it is important that you help the children and make them aware of the possibilities of how to prototype something. By giving the children a lot of different materials they are able to choose what they can use best in their prototype. However, another teacher also mentioned creativity lies within the constraints. So it is all about the right balance between enough to variate and not too much and overwhelm the children.
While coaching during the process it is the job of the teacher to ask a lot of questions and help the children in simplifying their idea so they can prototype it, start small and simple. Teachers need to be aware of their own way of working and do not push children in their preferred way of working. When a group is working together well, let them work as they do. The interviewees also mention that it is good to let the children reflect on what they are doing and let them think of questions themselves.

2.2 Observations

In order to understand how children currently go through the process of making a prototype, observations in three classes of different primary schools were made. The classes worked on the project 'Time', a project of Municipality Delft and Science Hub TU Delft. The observations are from when each class went to Science Centre Delft to make their prototype. One class was also observed the lesson before they went to Science Centre Delft. This provides a better understanding of with what knowledge and preparations the children went to the prototyping session in Science Centre Delft. The knowledge and preparations the children have beforehand influence their capabilities. During the observations the teachers were also present and answered some questions in order to get a better understanding of the skills and knowledge the children already have and use the experiences the teachers already have.

Group work

In multiple classes it was noticeable that working together on the same thing is important. A child mentioned the following:

> *" Are we doing separate ideas again?... "*

He said it with such a tone of voice that it was clear to me that he hoped that they would start to work on the same idea.
There was a group that was not agreeing on what to do. Every time one half had made something, the other half would undo it and implement their idea, so they were undoing each other's progress. After 1 hour and 15 minutes of working this group ended up with a piece of cardboard wrapped in wallpaper (see Figure 8).

Figure 8. *Prototype of a group that did not work together*

In some groups the collaboration was going well. They communicated well about who was doing what and would let each other know when they needed help. Before they would start doing something they would check what ideas others had. In one group the good collaboration led to a well thought through prototype (see Figure 9).
There were multiple groups that had clear leaders. For some this means that one child decided everything. Other groups used a more democratic approach and voted about decisions.
The size of the groups influenced the collaboration. A group of 5 children is too big, groups of 3-4 worked better. Members of the 3-4 groups were more often contributing to the process than the members of a group of 5.

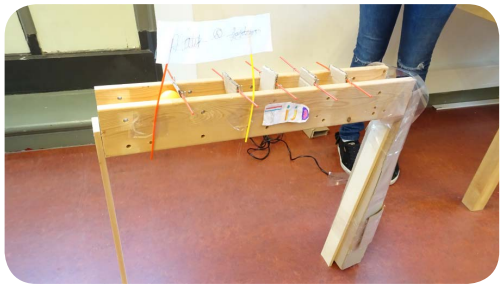


Figure 9. *Prototype of a group that worked together*

Guidance

Several teachers mentioned that the children need help and guidance in their process. One said it is important that you give the children clear boundaries within which they can choose. They mentioned they help the children often by asking a lot of questions. Children see their teacher as an expert.

> *" Sir helped us and he knows what we have to do. "*

Sometimes it is hard for the children to ask for help when they need it. There was a girl doing nothing for a long time and she started to help other groups by picking materials for them. One of the teachers had to ask her if she needed help, before she got the help needed to continue on her own project.

Goal

It was interesting to see that only a few groups had some kind of goal while making their prototype. For one group it was important that the signs on their prototype were visible, so in between they checked if they could see it from a distance and stepped further away to check if it was still visible. Another group made a thought through decision to only make a part of their idea and which part then.

> *" Making the whole thing is too much. "*

For most groups it was not clear what the goal of their prototype was, or they were not able to explain well why they did certain things.
When talking to the children and teachers it became clear that children see a prototype differently than teachers. According to the teachers the children had made prototypes before, but according to the children this time was the first time. So for the children a prototype is more specific than just making (a part of) your idea tangible.
Some groups had small reflection moments in their process. One group started counting the amount of elements they had to check if they still had enough. Another group was discussing what still had to be done before they were finished.

Clear tasks

Most groups did not have a clear plan with tasks before they started making. For some groups this led to confusion and they would lose their understanding on what they were doing.

> *"I don't know anymore. No, like this.. right?"*

Other groups had members that were not doing anything and started messing around.

> *"What are we going to do now?"*

After asking what was left to do, the child started messing around since he did not receive an answer.
In other groups there were members that just looked at what others were doing for quite some time.
It seems that some groups did have a plan, but this was in their head. A group looked critically at what they were doing and only continued working when it was clear again what to do next.
In the lesson before the session in Science Centre Delft, the whole class just started working on making their idea tangible. None of the groups started with a discussion, they all started with getting materials and building.
One group mentioned that they found it difficult to transform their 2D sketch to a 3D model to test with. They missed clear steps in how to approach this process.
In one session the teachers had prepared an optional step-by-step instruction for each group. Per step it mentioned what had to be done to get to a prototype. Most groups wanted to understand the instructions and follow them. When a group got stuck they looked back at the step-by-step instruction together with their teacher and followed the steps.

Materials and tools

The materials available for the children influence their capabilities. One group was looking at the materials that they had available and were looking at a way to use the materials for making their mechanism. At the end this group found out that there were more materials they could use than the materials on their table. They were a bit frustrated that they did not know.

> *"Then we could have made it much better."*

At Science Centre Delft more materials were available than at the schools. This does not immediately mean the children could do more or do things better. One group mentioned that it was nice that there were more materials available, but that they did not know how to use it all.

> *"Here you don't know how to use it."*

Children are curious of how things work. In the lesson before the session in Science Centre Delft, the children asked a lot of questions about the possibilities at Science Centre Delft.

2.3 Literature review

For this research it is meaningful to know what the advantages of and pitfalls during prototyping and going through a design process are. Furthermore, it is also relevant to know how design processes and prototyping specifically go in primary education. In order to find relevant papers combinations of the following terms are used in a search on Google Scholar: prototype, prototyping, approach, design process, (primary) education. Relevant papers found via Google Scholar are also used to find new papers via the references.

Using prototypes

As mentioned by Nieveen *(1999)* prototypes are often used multiple times by experts in a design process. Prototyping is a key element in the design process *(Berglund & Grimheden, 2011)*. From the literature it also becomes clear that prototypes are used for several goals. Menold, Jablokow & Simpson *(2017)* mention the following purposes: communicate ideas, gather user feedback, explore parallel design concepts, and make decisions. You can prototype for feasibility, desirability and viability. In a later paper Menold, Simpson & Jablokow *(2019)* state that a prototype is something that represents the design or parts of the design and that making prototypes improves the communication in a team. According to Wensveen & Matthews *(2014)* you can variate with the dimensions of a prototype: appearance, functionality and interactivity.

So experts use prototypes in their design process, but what is the value of prototyping? The literature mentions several values of prototyping. Berglund & Grimheden *(2011)* state that prototyping is one of the key factors in creating innovation, as well as it being fundamental in reaching higher quality products. This last aspect is backed by Deininger et al. *(2017)*, they state that prototyping minimizes the errors a design has.
According to Menold et al. *(2017)* you can get more meaningful information from your user group and communicate about it by prototyping. Prototyping also increases the likelihood that the product will succeed, since you can identify the unknowns of a design and its main characteristics *(Menold et al., 2019)*.

In the design process there is not one clear moment where you have to use prototypes. You can use prototypes in different stages and forms during your process *(Deininger et al., 2017)*. Related to this is that every prototype has its own goal and focus *(Nieveen, 1999)*.

Approach of prototyping

As mentioned before, every prototype has its own goal. When you have a question you want to find an answer to, it is important that you use the right approach for that specific question *(Deininger et al., 2017)*. Using a method while prototyping is also beneficial for the process *(Menold et al., 2017)*. And a structured framework for prototyping leads to a higher quality design *(Menold et al., 2019)*. Not just all frameworks will be beneficial for your process. It is important that the framework is flexible and allowing the designers to choose the level of fidelity and materials they want to use that fits their stage of the process *(Menold et al., 2017)*. It should also enable the designers to involve their users to gain better insights into their product *(Menold et al., 2017)*. A framework for prototyping should stimulate making early and multiple prototypes and making it an iterative process. It should also enable teams to select a clear goal for their prototype before they start making. This all should lead to effective decision making *(Menold et al., 2017)*.

Camburn et al. *(2015)* addresses the importance of creating a planning of your prototyping process. By doing this it will be easier to go through the process since you are more aware of the uncertainties. Next to planning Camburn et al. *(2015)* states three more successful factors of a prototyping strategy: parallel concept testing, iterative testing and requirement specification.

Frequency and timing of prototyping

Literature mentions several things about the frequency of using prototypes and about the timing. Menold et al. *(2017)* state that making more prototypes leads to better results, creates space for richer discussions about the concepts, and creates a better understanding of the technical and functional constraints.
By creating multiple prototypes in a row you are iterating. According to Berglund & Grimheden *(2011)* prototyping phases consists of iterations, which improves performance *(Camburn et al., 2015)*.

Next to iterating on a prototype, it can also be beneficial to use parallel prototyping. With parallel prototyping you can achieve higher performance of your final prototype *(Camburn et al., 2015)* and increase the quality of your design *(Menold et al., 2019)*.

Using prototypes in an early stage of the process and using it iteratively throughout the process helps designers in creating a better design, it can be done quickly and does not have to be expensive *(Deininger et al., 2017)*. Applying prototypes in an early stage also increases the efficiency of the process *(Menold et al., 2017)* and improves the technical quality of the end design *(Menold et al., 2018)*. By starting early you help in visualising problems and find incorrect design assumptions *(Menold et al., 2019)*.

Level of fidelity of prototype

Prototypes do not have to be very complex to have a good contribution to your process. The level of fidelity of a prototype does influence the type of information and insights you can gather with the prototype *(Menold et al., 2017)*.
When you create low fidelity prototypes early in the design process the functionality of the end design improves *(Neeley, Lim, Zhu & Yang, 2013)*.

You can prototype parts of your idea. Yang *(2005)* states that prototypes with fewer parts are more successful and lead to a better design outcome. You do not have to prototype a complete system to find out if certain parts do what they should do *(Camburn et al., 2015)*.
Creating small prototypes also enables designers to iterate more and therefore generate a better solution for their problem *(Deininger et al., 2017)*.
It can be beneficial to start with prototyping a small element of your idea, instead of starting with the full idea. This way you keep your process manageable and enable yourself to learn from the failures and successes *(Nieveen, 1999)*.

Design processes in primary education

Design assignments are being implemented in primary school education. McFadden & Roehrig *(2019)* state that implementing moments of reflection throughout the process of prototyping creates small iterations in the process. And as mentioned before, this enables designers to achieve higher quality designs. Looijenga, Klapwijk & de Vries *(2015)* also mention that iteration is one of the aspects to improve the effectiveness of design activities. The other three are: freedom of choice, collaboration and presentation.
To enable children to perform and do a task, goals and expectations need to be clear *(Looijenga, Klapwijk & de Vries, 2018)*.

Learning in design processes in education

In-depth learning is facilitated by prototyping activities *(Berglund & Grimheden, 2011)*.
The design process, with iterations fits the natural way of learning from children *(Looijenga et al., 2015)*. Their natural way of learning is by iterating.
After repeating an activity children get more sense of control *(Looijenga et al., 2015)*.
Another way for children to learn is through discovery with a simple task *(Looijenga et al., 2018)*.
Looijenga et al. *(2015)* also mention that, next to repeating an activity, children also learn from seeing the results from other groups. This gives them a bigger perception of the possibilities.
Wendell & Lee *(2010)* state that when you want children to get the most out of learning, you need to let them reflect on their activities.
In the paper of Looijenga et al. *(2018)* they bring up the importance of giving clear tasks and boundaries to make sure they do not get overwhelmed and stop learning. They also mention that it is beneficial for the results and learning process of the children to split a complicated project into several doable tasks.

Materials in design processes in primary education

Without materials it is hard to prototype something, but does the material influence the children in their process? McFadden & Roehrig *(2019)* state that when children have access to the materials for making, it enables them to talk about imagined constructions and evaluate their designs. They also mention that with the materials in hand the children are able to reflect on their prototype and adjust it where necessary.
Looijenga et al. *(2015)* mention a way to stimulate children's creativity is to let them learn in a natural way and give them some materials to play and experiment with.

Communication in design processes

Design assignments are often tackled in groups, so communicating becomes an important aspect in the team. Wendell, Wright & Paugh *(2017)* state that when children use pronouns during the process of design with a group, it obstructs the collaboration since it is not clear what they are talking about.
For groups to effectively communicate it helps if they have drawings of their design *(Anderson, Courter, McGlamery, Nathans-Kelly & Nicometo, 2010)*.

Facilitate design processes in primary education

McFadden & Roehrig *(2019)* mention it is not easy for a primary school teacher to facilitate a design process. It is different from the way they are used to teach. This can lead to the teachers forgetting about the iterative nature of a design process and present the process as linear to the children.
For the teachers it is important to keep in mind that they should ask a lot of guiding questions, starting with open questions to more closed questions but still open enough for the children to draw their own conclusions *(McFadden & Roehrig, 2019)*. When asking guiding questions it is also important to not only ask about conceptual aspects, but also help with more practical aspects *(Wendell & Lee, 2010)*.
For teachers to provide meaningful feedback to students making prototypes they should not fixate on the materials used but look at what they are trying to achieve and focus on those goals *(McFadden & Roehrig, 2019)*. In their research McFadden & Roehrig *(2019)* also mention it might be better to give children written feedback instead of verbal feedback, this way the teacher can overthink the wording and help the children to overcome their uncertainties without limiting the imaginations of the children.

Prototyping for novice designers

As mentioned in the introduction, novice designers often do not fully use making prototypes in their design process *(Deininger et al., 2017)*. Novice designers are unaware of the advantages of making prototypes and how to use them. They often see prototypes as something to do at the end of the project to test and evaluate the design, instead of letting play a role in various stages of the process to help developing the product *(Deininger et al., 2017)*. For novice designers it is hard to see how they could benefit from prototyping and how it could lead to insights to get further in the process and have a better result *(Deininger et al., 2017)*. In their research Deininger et al. *(2017)* mention it takes practise to see the benefit of prototyping and know the right approaches in different stages. Participants in the research of Deininger et al. *(2017)* mention that they

benefited in their prototyping process by making a plan on forehand.

Target group

In research of Looijenga, Klapwijk & de Vries *(accepted of 2020)* they mention several things regarding the target group of this project. They state that well-defined tasks are useful in initiating engagement. When you give well-defined tasks it provides insights of what is possible and impossible. Lastly, they also mention the value of looking forward and backwards. Looking forward helps in anticipating and looking backwards helps in finding flaws and therefore create a better (re)design.

2.4 Conclusions

From the interviews, observations and literature review several conclusions can be drawn. In this section the most relevant conclusions are listed which will be used in setting criteria for the design intervention.

Core of prototyping

From the literature *(Nieveen, 1999)* and interviews it became clear that one of the most important things children should experience in a design process is that it is an iterative process and that you prototype to find something out. One of the key features of a design process is namely that it is an iterative process. Designing is something everyone can do as long as you follow the right methods.
The definition of a prototype differs for children and teachers. Children do not fully understand the usefulness of a prototype, when something is called a prototype and what the intention of prototyping is.

Kind of prototype

In a design process experts use prototypes multiple times in different stages of the process. Each prototype has its own goal and focus. Literature *(Camburn et al., 2015)* shows that next to iterating on one prototype, you can also use parallel prototyping, creating multiple prototypes at the same moment.
A prototype can be very simple and existing of just a few parts and give you just the right information you needed. Literature shows that by creating small prototypes you can produce more and iterate more in your process.

Approach

Literature *(Camburn et al., 2015; Menold et al., 2017)* shows that in order to optimise your prototyping process it is important to have a clear planning, in which you also thought about the level of fidelity and materials that fits with your goal. Interviews and observations also show the importance that children know what they want to do and why. They should have a clear plan and goal in mind for their prototype.
Literature *(Looijenga et al., 2018)* and observations show that goals and expectations need to be clear for children in order for them to be able to perform and execute the task.

Tasks

During the observations it became clear that when the tasks that need to be done in the design process are not clear, or when there are not enough tasks for all group members, children often go off track and stop contributing to the progress. They might start messing around or just do things that are not related to their project.
A way an interviewed teacher uses to make sure all group members of a design team have a task while prototyping, is to have them create two prototypes.

Group communication

Observations show that good communication in a design team has a positive influence on the quality of the end result. Groups that communicate well deliver better and more complete prototypes than groups that have members that just do what they want.
Literature *(Wendell et al., 2017; Anderson et al., 2010)* also shows that good communication in a team is key to better results. It is important that all group members use a common language and understand each other when discussing aspects of their design (process).
An element that helps in good communications is having clear drawings.

Reflection

Literature *(McFadden & Roehrig, 2019)* shows that reflecting on what you do also creates small iterations in your process.
Children learn from seeing the results of others and reflecting on their own activities.
Literature *(Looijenga et al., accepted of 2020)* also shows that looking forward helps children to anticipate on what is coming.

Freedom of choice

In a design process you want children to be creative and according to the interviews you can stimulate creativity by providing a limited amount of materials. On the other hand, seeing a lot of materials and options can inspire you as well. Therefore, it is important to find the right balance in material supply.
Interviews show that children need clear boundaries within which they can choose in order for them to be able to perform and execute tasks.

Learning behaviour

According to literature *(Looijenga et al., 2015)* iterating fits the natural way of learning from children. After repeating activities children get more sense of control over what they can do.
Literature *(Looijenga et al., accepted of 2020)* also shows that a well-defined task initiates engagement from the children.

Skills and knowledge

Interviews and observations show that in order to create a prototype it is important that you possess the necessary skills. So for children this means that they know what materials and tools they can use and how to use those. Before they can use the materials and tools in their context they need to have explored the possibilities.
Literature *(Looijenga et al., 2015)* shows that the creativity of children can be stimulated by letting them learn in their natural way by playing and experimenting with materials.

Materials

The materials available influence the capabilities to prototype something. Interviews show that schools do not have a big budget available for materials, so often use cheap and/or waste materials. It can also be useful to have materials available that can be used and reused in multiple ways.
Observations show that having several (new) materials available is something children appreciate, but only when they know how to work with the materials.
Literature *(McFadden & Roehrig, 2019)* shows that when children have access to the materials available for prototyping it enables them to talk about imagined constructions and evaluate the design they created.

Facilitating

According to the interviewees the role of a teacher when facilitating a design process is to ask a lot of questions, stimulate the children to think of questions themselves too, and let them reflect on what they are doing. Each group has its own way of working, so the teachers should keep in mind that there is not one way that is correct.
Observations show that children see the teacher as an expert in designing.
Literature *(McFadden & Roehrig, 2019)* shows that for the teachers facilitating a design process it is important that they do not forget about the iterative nature of the design process. They should ask a lot of guiding and open questions which still enables children to draw their own conclusions. Lastly, when helping a group it is important to not fixate on the materials used by the group but look at their goal and how it can be achieved.

3. Design direction

All the information gathered in the research phase let to two design goals and a list of criteria for the solution for the design goals, see Appendix 3. The criteria are translated in requirements for the solutions and are listed in this chapter.

3.1 Design goals

In the research phase it became clear that prototyping is hard for children to do, but also hard for teachers to facilitate. Both groups will influence the meaningfulness of prototyping, therefore there are two different design goals. One goal, the main goal is focused on the children and the second goal is focused on the teachers.

The main goal is:

1) Make children (9-12 years) use prototyping to iterate in their process by supporting them in the why and how they can prototype.

Since the teachers have a big influence on the capabilities of the children a second design goal is as following:

2) Support teachers in coaching the children through the process related to prototyping.

Two design goals means that the solution will exist of at least two parts. The assignment for this project is to create a tool which supports children. Therefore, there will be a tool for children (design goal 1) and a tool for teachers (design goal 2).

3.2 Requirements and wishes for design goal 1

The tool for design goal 1 will have to meet some requirements that derived from the research. Next to the requirements there are also a few wishes derived from the research, which would be preferable if the tool meets those too. The requirements and wishes are listed below.

Requirements

Stand-alone tool

R1.1 The tool should be self-explanatory for teachers.
R1.2 The tool should be usable for almost all children in mainstream education.

Core of prototyping

R1.3 The tool should stimulate iterations.
R1.4 The tool should force children to set a goal for their prototype.

Moment of prototyping

R1.5 The tool should be applicable in multiple phases.
R1.6 The tool should be applicable multiple times during a design process.

Approach

R1.7 The tool should force children to create a clear plan with what needs to be done, how and by whom.

Reflection

R1.8 The tool should provide reflection moments on the progress and process of the children.

Skills and knowledge

R1.9 The tool should provide the children with knowledge of different goals to prototype for.
R1.10 The tool should provide the children with knowledge of different ways to prototype.
R1.11 The tool should stimulate children to learn new skills which can be applied in prototyping.

Wishes

W1.1 The tool should allow teachers to adjust the format to their preference.
W1.2 The tool should be self-explanatory for children.
W1.3 The tool should provide enough tasks for prototyping to enable all children to contribute to the process.
W1.4 The tool should make the children reflect in depth on their process.

3.3 Requirements for design goal 2

The tool for design goal 2 will have to meet other requirements that derived from the criteria than the tool for design goal 1. The requirements for the tool for design goal 2 are listed below.

Requirements

R2.1 The tool should be understandable for almost all teachers in mainstream education.
R2.2 The tool should provide the teachers with knowledge on the design process related to prototyping.
R2.3 The tool should provide the teachers with dos and don'ts in facilitating a design process related to prototyping.

4. Elements of the design

To reach both design goals several tools with multiple elements are developed. In this chapter all the elements are introduced and in the following chapters the elements are explained in detail.

Figure 10 shows all the elements that are developed and how they contribute to reaching both design goals.

4.1 Possible process

Figure 11 (next page) shows a possible process a teacher and children could go through when using the elements of the design.
All elements can be used separately, but it is recommended to use the Skill tool before using the Iteration tool when children are not very skilled in prototyping. It is also recommended to use the Prototype-discussion-game before the Iteration tool when children are not very familiar with different goals prototypes can have.

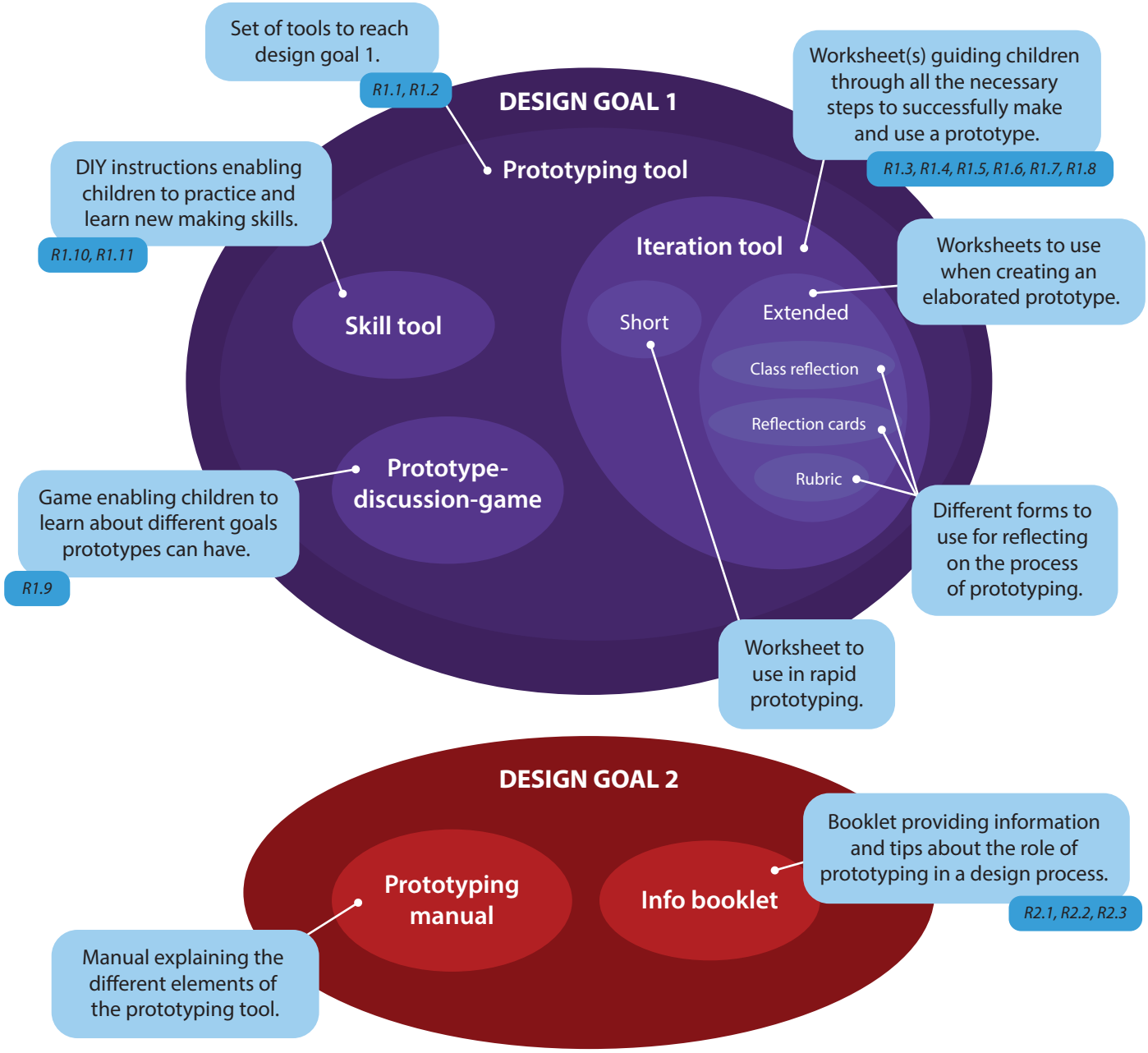


Figure 10. *Overview of all the elements of the design*

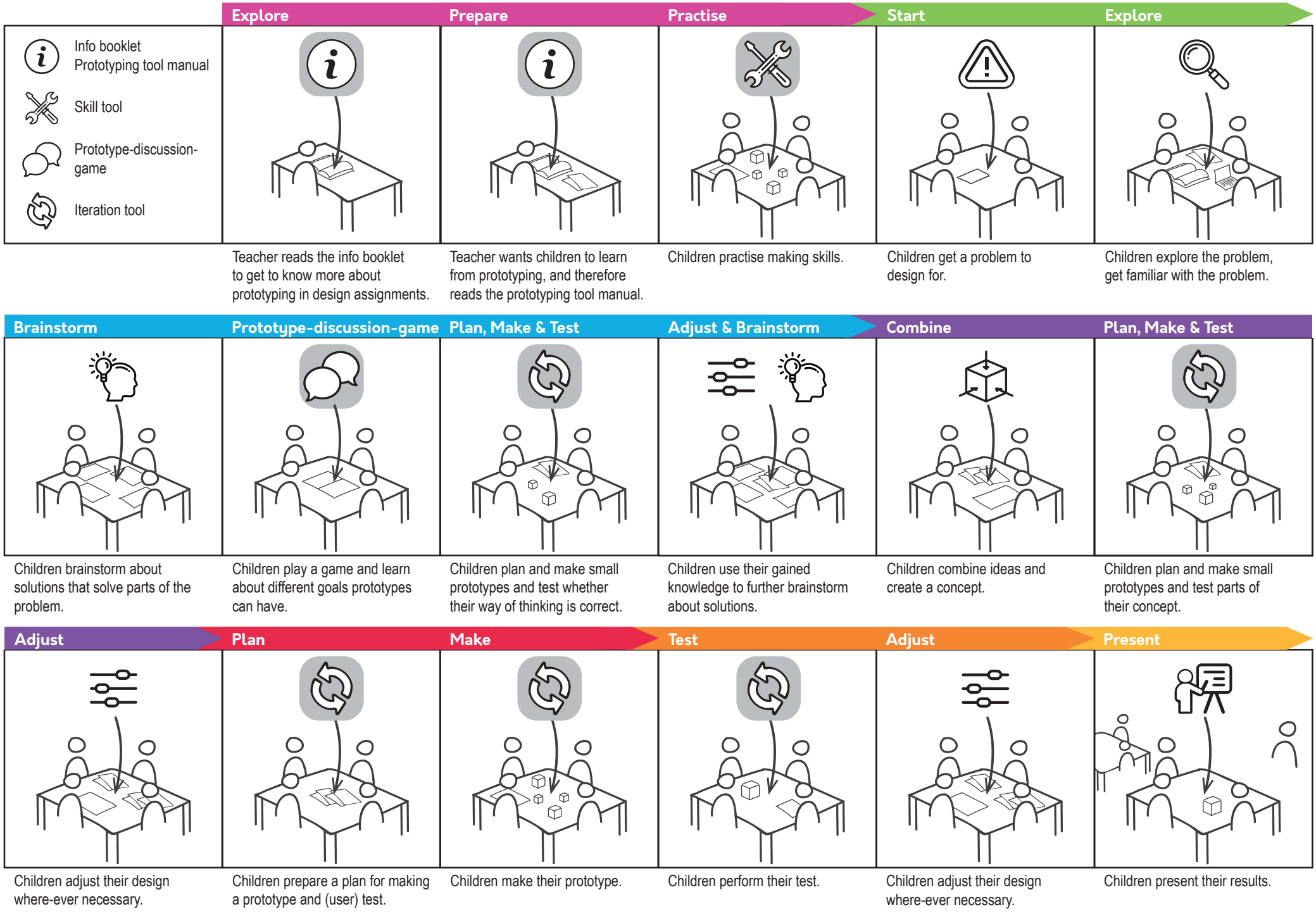


Figure 11. *Possible process for implementing the design elements in class*

4.2 Iterating

Design goal 1 is to have children use prototyping to iterate in their design process. In order to create a fitting tool, you need to know what iterating means and what you are doing when you are iterating. The core of iterating is looking forward and backwards. This translates in the model shown in Figure 12. You have a starting point, look forward, create something, look backwards and adjust it if necessary. Then you enter the same cycle again starting from looking forward. This allows you to iterate. The Iteration tool is developed to help children iterating in their design process by making prototypes.

At the moment children often only prototype in phase 4 of the design cycle, 'Building a prototype. There are more opportunities for the children to apply making a prototype to get further in their design process (see Figure 13). Phase 2, 3, 4 and 5 are phases in which you can prototype as well and therefore, use the Iteration tool.

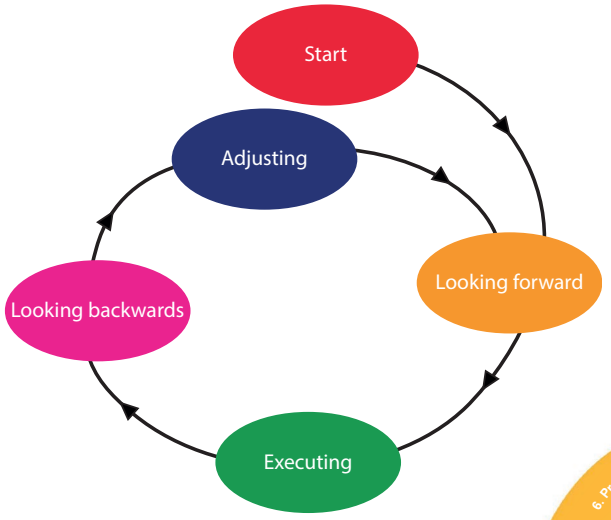


Figure 12. *Iteration model*

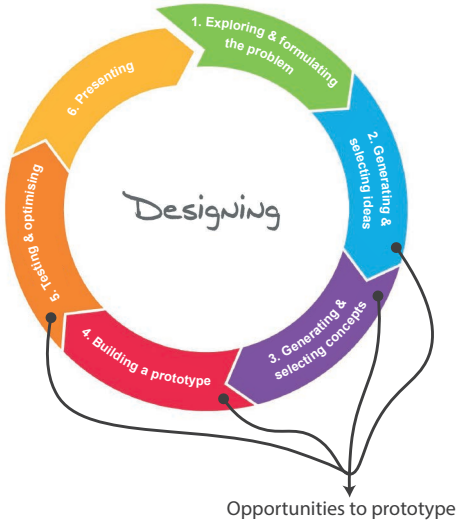
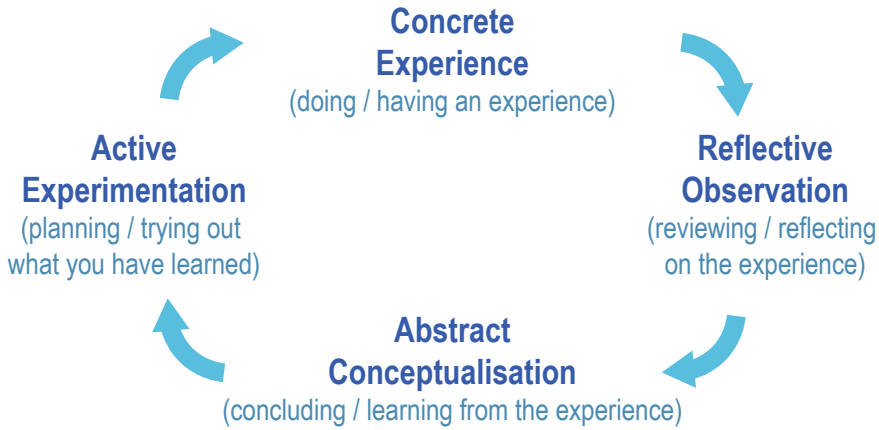


Figure 13. *Phases in which you can apply prototyping*

4.3 The Experiential Learning Cycle

Effective learning can be seen when a child goes through the four stages of the Experiential Learning Cycle (ELC) *(McLeod, 2013)*. Figure 14 shows the four stages of the ELC. With the developed tool children should be able to learn about prototyping and how to do it, therefore the tool should guide the children through the four stages of the ELC.

There is critique on what Kolb has developed, but this critique is mainly on the learning styles *(Garner, 2000)*. Garner *(2000)* states that ELC shows the necessary stages within the learning process. This project uses the ELC of Kolb and not the learning styles.



1. **Concrete Experience** (a new experience of situation is encountered, or a reinterpretation of existing experience).
2. **Reflective Observation** (of the new experience. Of particular importance are any inconsistencies between experience and understanding).
3. **Abstract Conceptualization** (Reflection gives rise to a new idea, or a modification of an existing abstract concept).
4. **Active Experimentation** (the learner applies them to the world around them to see what results).

Figure 14. *Kolb's Experiential Learning Cycle (McLeod, 2013)*

4.4 Flowchart

Since the elements of this design can both be used together and separate from each other, a teacher has to make a few decisions about what (s)he wants to use. Figure 15 shows a flowchart of the designed elements.

A teacher can choose to use all the design elements and follow the blue path. In this path the teacher has to choose whether (s)he wants to use the Short version or Extended version of the Iteration tool. When a teachers chooses the Extended version, (s)he has to choose for one of the three types of reflection.

A teacher can also choose to skip the Skill tool (orange path). From this point a teacher can decide to only use the Prototype-discussion-game, or continue on the blue path and also use the Iteration tool.

Another option is to skip both the Skill tool and Prototype-discussion-game (green path) and only use the Iteration tool. The teacher still has to choose between the Short and Extended version (blue path).

Lastly the teacher can decide to use the Skill tool and skip the Prototype-discussion-game (pink path). From this point the teachers can decide to only use the Skill tool or also use the Iteration tool and continue on the blue path.

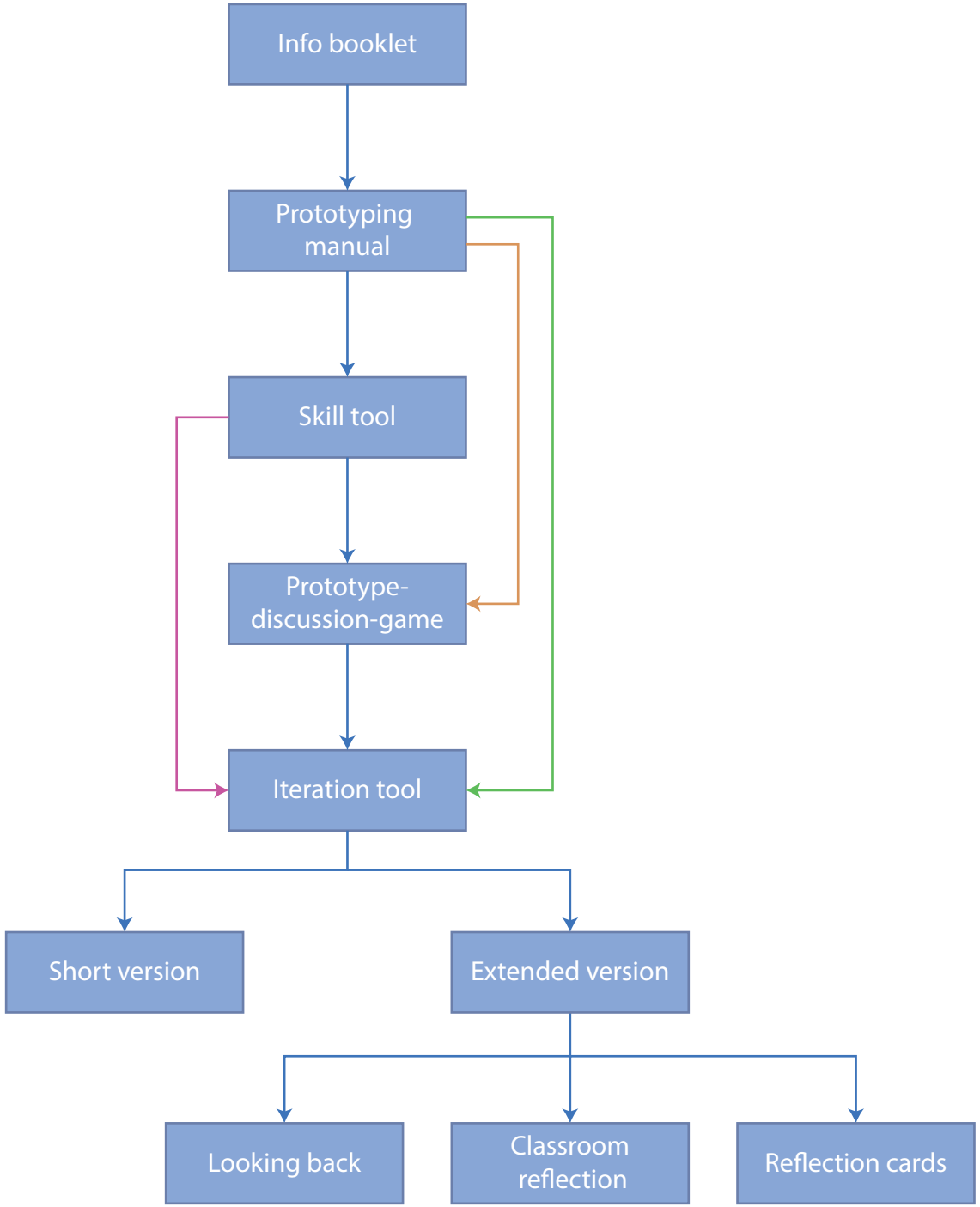


Figure 15. *Flowchart of designed elements*

5. Skill tool

The Skill tool is meant to teach children new 'making skills'. Making skills means, skills that can contribute in making a prototype (more easy). From the interviews with primary school teachers it became clear that schools do not have a big budget to buy a lot of prototyping materials, ± €40,- for a whole year. Therefore, the Skill tool focusses on materials that are cheap and/or are already used in primary education.

5.1 DIY-instructions

The Skill tool exists of several Do-It-Yourself (DIY) instruction forms. Figure 16 gives an overview of the recurring elements in the DIY instruction forms. The forms give a step-by-step instruction in text supported by images to make more clear what is meant in text. The last step of all the forms is the same, "use what you have just learned in creating a product". In this way the children learn to apply their knowledge without constraints, what hopefully will help them later when designing and prototyping a product for a specific design assignment.

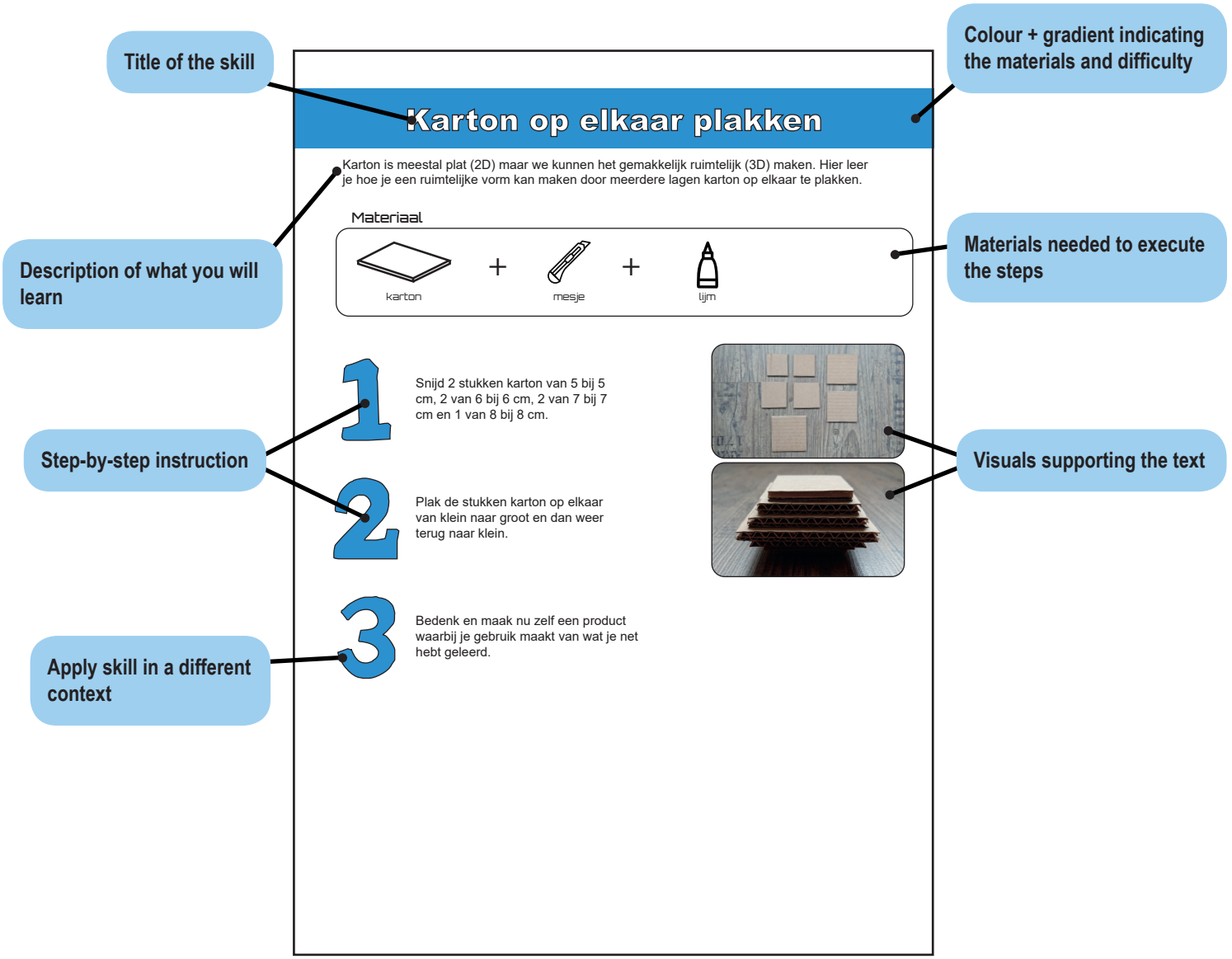


Figure 16. *Recurring elements in the DIY-instruction forms*

5.2 Making skills

As mentioned before the Skill tool focusses on materials that are cheap and/or already used in primary education. The materials are the starting point of each skill. Via the knowledge of the researcher and an online research, the different making skills derived based on how you can process the materials. Table 1 shows which making skills are part of the Skill tool.

Making skill	Materials needed	Colour code
Sliding cardboard into cardboard	cardboard, knife	Blue
Connecting cardboard using tape	cardboard, knife, tape	Blue
Folding cardboard	cardboard, ruler, pencil	Blue
Connecting cardboard using cotter pins	cardboard, knife, cotter pin	Blue
Connecting cardboard using glue	cardboard, knife, glue	Blue
Deforming iron wire	iron wire, pliers	Orange
Creating an axle using chopsticks and straws	chopstick, straw, scissors, glue, wheels	Red
Creating a hinge using paper clips and straws	paper clips, straw	Purple

Table 1. *Making skills of the Skill tool*

5.3 Colour code

All instruction forms have their own colour and gradient. Skill cards that make use of the same materials have the same colour. The darkness of the colour indicates the difficulty level, the darker the more difficult the skill. The skills are ranked based on knowledge and experience of the researcher of this project.

5.4 Experiential Learning Cycle

The Skill tool covers the four stages of the ELC (see Figure 14 on page 26). The goal of the Skill is to teach children how they can make prototypes.
The 'Concrete Experience' is facilitated by giving the children a step-by-step instruction to follow. This allows the children experience a new skill. The 'Reflective Observation' (RO), 'Abstract Conceptualisation' (AC) and 'Active Experimentation' (AE) is facilitated through the last step where the children need to apply the skill they just learned in a different form. In order to perform this step the children need to reflect on what they have just learned (RO), create a new idea with what they have learned (AC) and shape their idea in something physical (AE).

6. Prototype-discussion-game

As mentioned in the introduction the Prototype-discussion-game is developed by a former student, Nadine Rodewijk. In this project the game is used to make the children aware of and familiar with different goals prototyping can have, since the research of Nadine and this project show that most children do not have a clear goal in mind while prototyping. The test done by Nadine showed a few points for improvement *(Klapwijk & Rodewijk, 2018)* of which she already implemented some, see Appendix 2.

6.1 How the game works

As mentioned before the goal of the game is to make children aware of and familiar with different goals prototypes can have. The game exists of two types of cards: goal-cards and prototype-cards (see Figure 17). The goal-cards have different goals for prototypes written on them and the prototype-cards have images of a prototype. Each child gets five goal-cards. They draw a prototype-card and everyone picks the goal-card from their hand that best fits the prototype-card. Once everyone chose a card, the groups needs to discuss and decide which of the chosen cards fits best. They repeat this for several prototype-cards.

6.2 Stimulating discussion

One of things that came from the test is that there was hardly a discussion about the chosen goal-cards, while they are meant to learn from the different options you have to prototype and why those are options. Therefore, the game should facilitate a discussion. By brainstorming, see Appendix 4, a solution for this problem was found.
The children get a playing field which shows that there need to be pairs created. The idea is that this will stimulate to talk about the cards on the table, since they can see what steps still need to be done.
Stimulating the children is preferred over forcing, since it should still be enjoyable to do and you cannot control all things children do. Adding another game element would also have been an option, but then it would indirectly suggest that there is a good and wrong, while the idea is that when you can argue your choice it is a good choice.
In an older version of the adjustment of the Prototype-discussion-game, the playing field exists of only a few rectangles which indicated the spots the place the cards.
In the last version (see Figure 18 on the next page) the playing area is made more attractive for children by adding colours and symbols to make it more look like a board of a game. The field exists of two portrait A3 papers.

6.3 Updating cards

In order to make the prototype-cards and goal-cards of the game more align and visually attractive, a few adjustments to the cards are made. There is an icon and coloured border added to the prototype-cards. In this way the playing field and cards use the same design language (see Figure 17).

6.4 Novice and expert users

When children are not familiar yet with setting goals, they should play the Prototype-discussion-game. After having played the game several times, playing the game will not be beneficial anymore and can be left out when going through the design cycle.

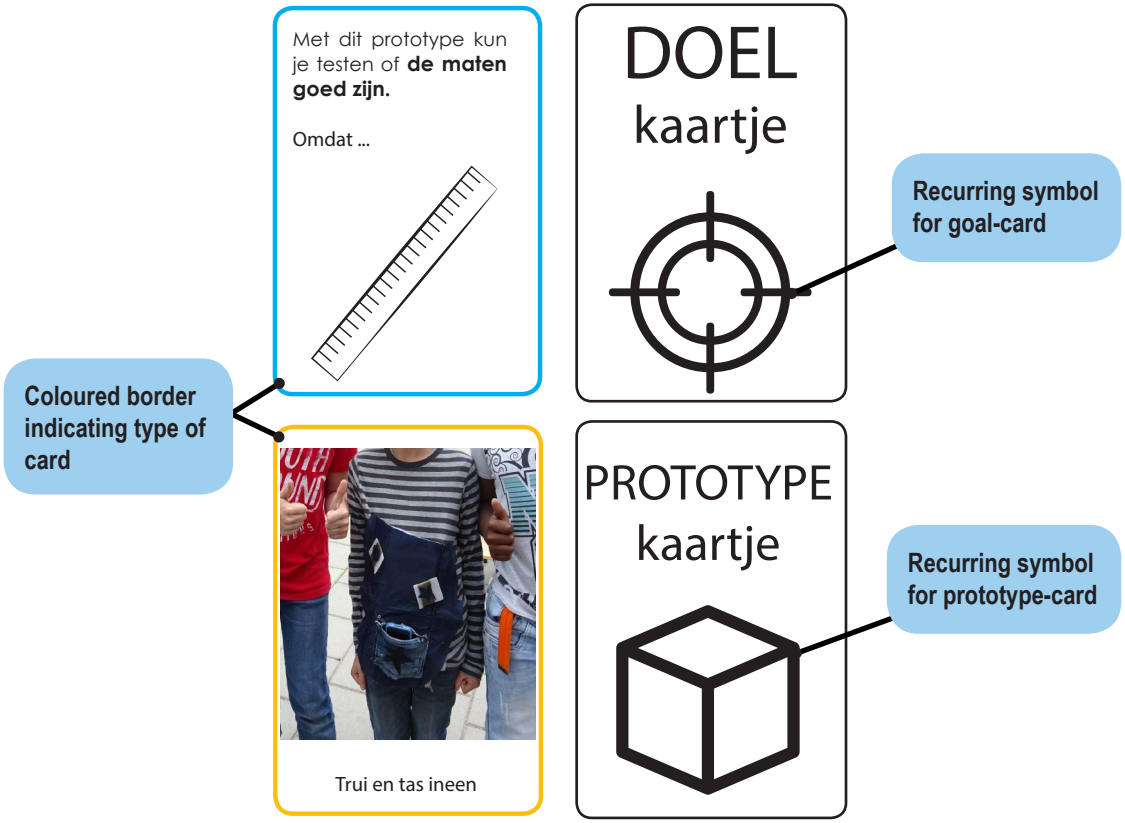


Figure 17. *Example of a goal- and prototype-card*

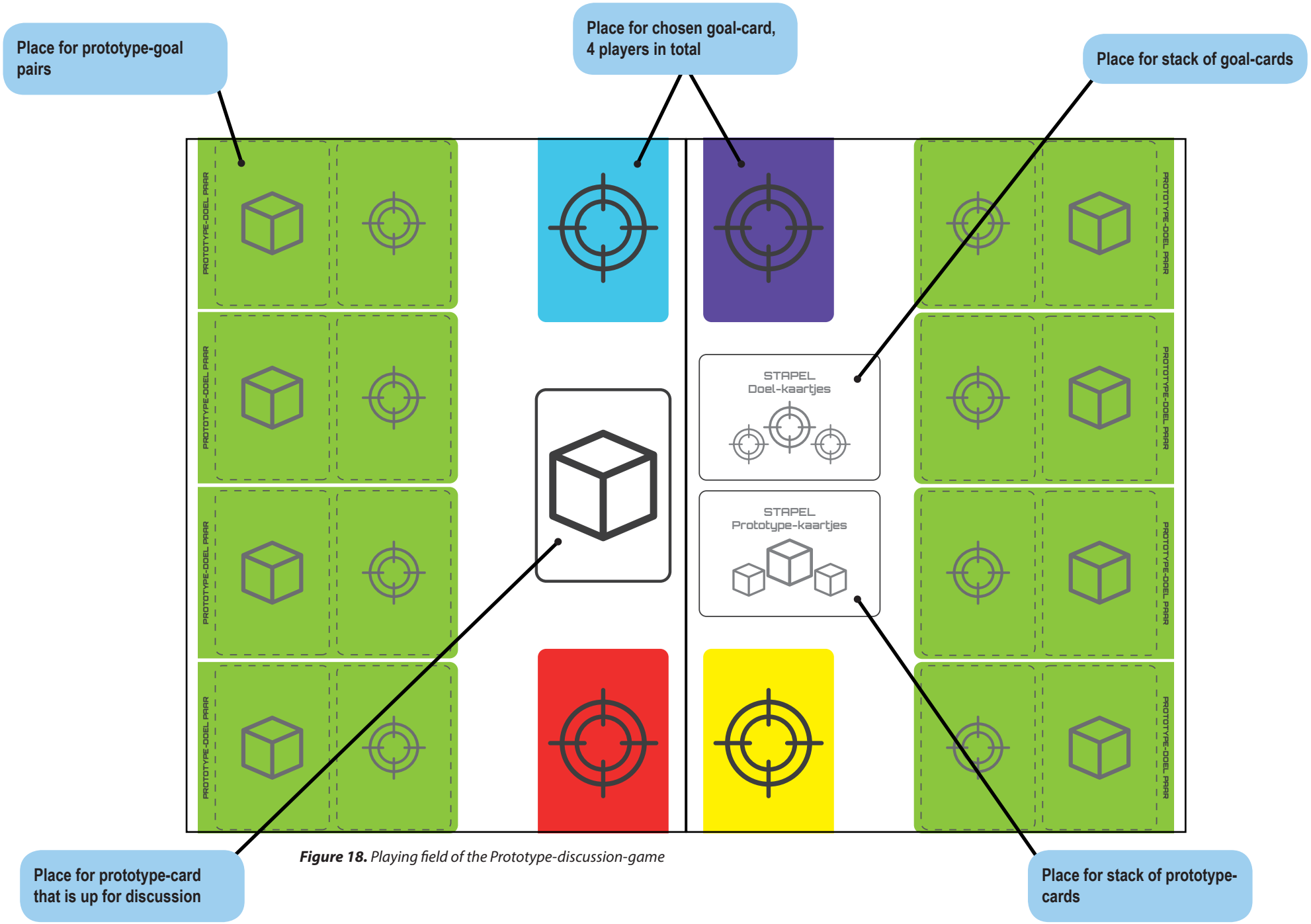


Figure 18. *Playing field of the Prototype-discussion-game*

7. Iteration tool

The Iteration tool is meant to help children iterate in the design process by making prototypes. In order to facilitate the children and the teachers the Iteration tool exists of several elements which can replace each other. The different elements of the Iteration tool allow teachers to adjust the form of the Iteration tool according to the skills, needs and wishes of the children and/or teacher.
Figure 19 gives a representation of the worksheets of the Iteration tool that children get and need to read or fill in.

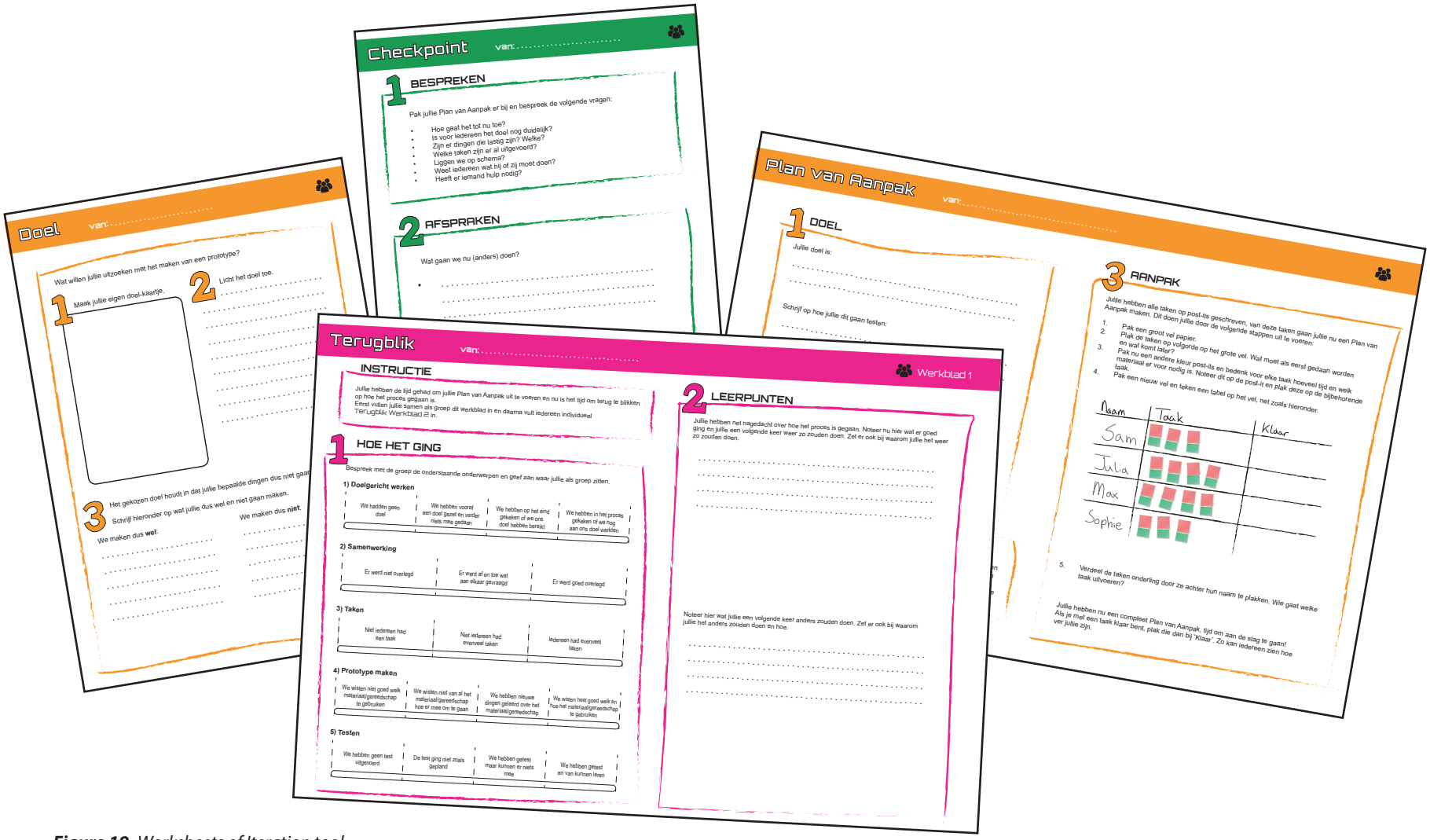


Figure 19. *Worksheets of Iteration tool*

7.1 Application of the Iteration tool

Figure 20 shows how the iteration model can be implemented in the design process.

Selected idea/concept

The starting point of the iteration cycle is an idea or concept. This is not necessarily an idea or concept that already has been thoroughly thought through. The cycle can start with just a small first idea or thought the children have.

Looking forward

When you have an idea and want to prototype, you prototype to find something out. When you want to test something, you need to have a clear goal before you start prototyping. In this stage the children set a clear goal for their prototype and create a plan of approach, so they all know what needs to be done. Setting a goal and making a plan enables the children to make the tasks concrete and clear. They make a list with tasks they think have to be done in order to test their goal. They put the tasks in

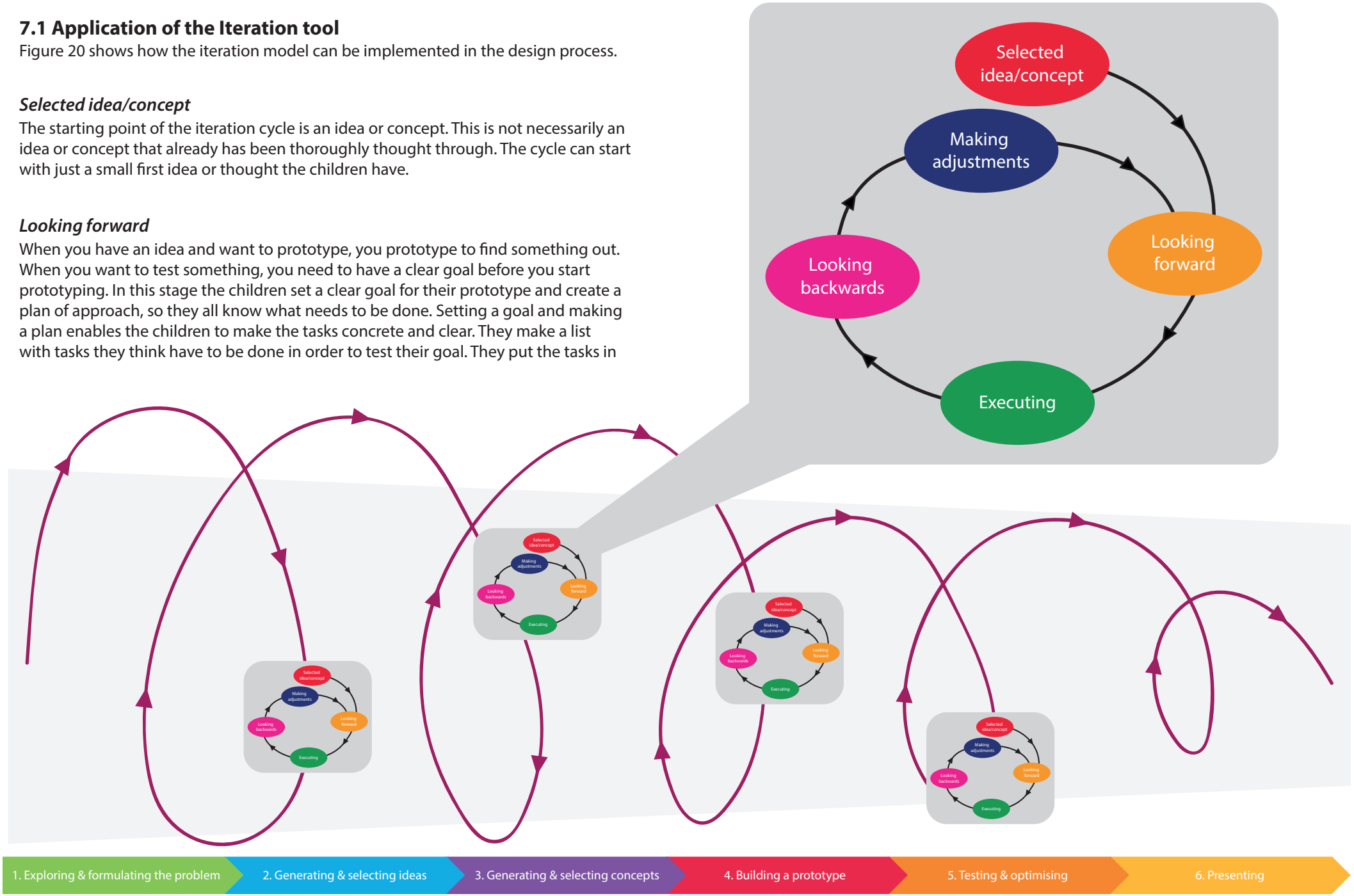


Figure 20. *Model of iterating in a design process*

chronological order, think of the time and materials needed for each task and assign the tasks to group members.

Executing

In this stage the children execute their plan of approach. Halfway in the process there can be a moment of reflection, a checkpoint. In this reflection the children make sure everyone still knows what to do and if they are still on track. Once their prototype is finished they can test their goal.

Looking backwards

After the children tested their prototype it is time to reflect on their process and prototype. In this stage the children are asked questions about their process which allows them to reflect on what they did and learn from it.

Making adjustments

In this stage the groups will adjust their designs according to their insights from testing. When they adjusted their design, they can start the iteration cycle again and this time with setting a new goal.

7.2 Elements of the Iteration tool

The Iteration tool consists of two versions, the Short version and the Extended version. The Short version can be used for quick prototyping and the Extended version for an elaborated prototype. The Extended version consists of multiple worksheets while the Short version consists of only one worksheet.
There are different ways to reflect on what you have done and using different ways can allow a group to think of and learn new things. In order to allow teachers to adjust the form of the Iteration tool that best fits their learning environment, the Extended version contains multiple reflection worksheets.
Figure 21 shows an overview of the worksheets of the Iteration tool and in what combination they can be used. It also shows to which stage of the iteration model the worksheets belong.

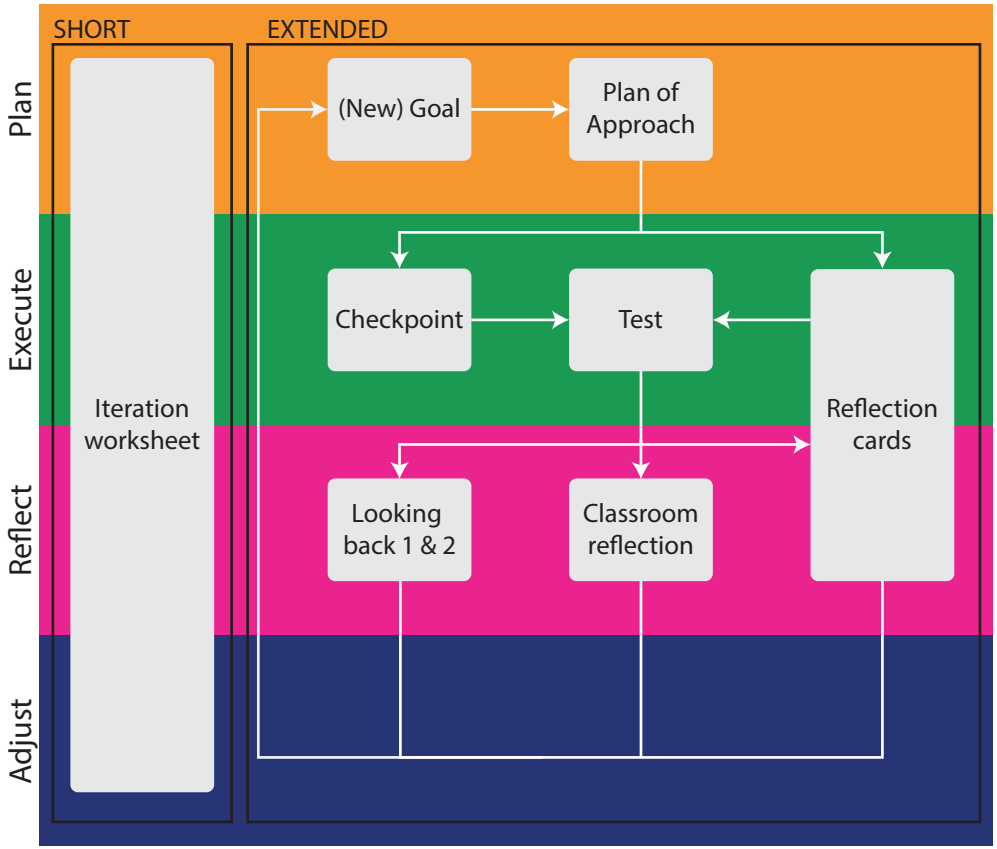


Figure 21. *Overview of the elements of the Iteration tool*

7.3 Extended version

The Extended version of the tool exists of 8 worksheets and a powerpoint presentation: Goal, Plan of Approach, Checkpoint, Test, Looking back worksheet 1, Looking back worksheet 2, Reflection cards, New goal and Classroom reflection.
Several versions of the worksheets have been made. The changes made are based on feedback from teachers and the supervisors of this project. For all worksheets a difference between the first version and the last version is that the writing assignments have been reduced and there is more white in order to make the sheets more approachable and inviting for children and allowing them to fill in the sheets in a way they prefer. The children are allowed to draw instead of write everything.
All worksheets have a colour that is linked to the stage of the iteration model (see Figure 12 on page 26) in which the worksheet is used. The use of the colours enables you to quickly distinguish the different worksheets. Next to colour all worksheets are equipped with a banner. The instruction forms of the Skill tool, Prototype-discussion-game and the worksheets of the Iteration tool have this banner to create a visual link between the tools that belong together to the Prototyping tool. The Skill tool and Iteration tool both use the same font for the numbers to indicate different steps that have to be taken. Lastly, all worksheets have an icon that indicates whether the worksheet has to be filled in as group or individually. Figure 22 indicates the recurring elements of the Iteration tool.

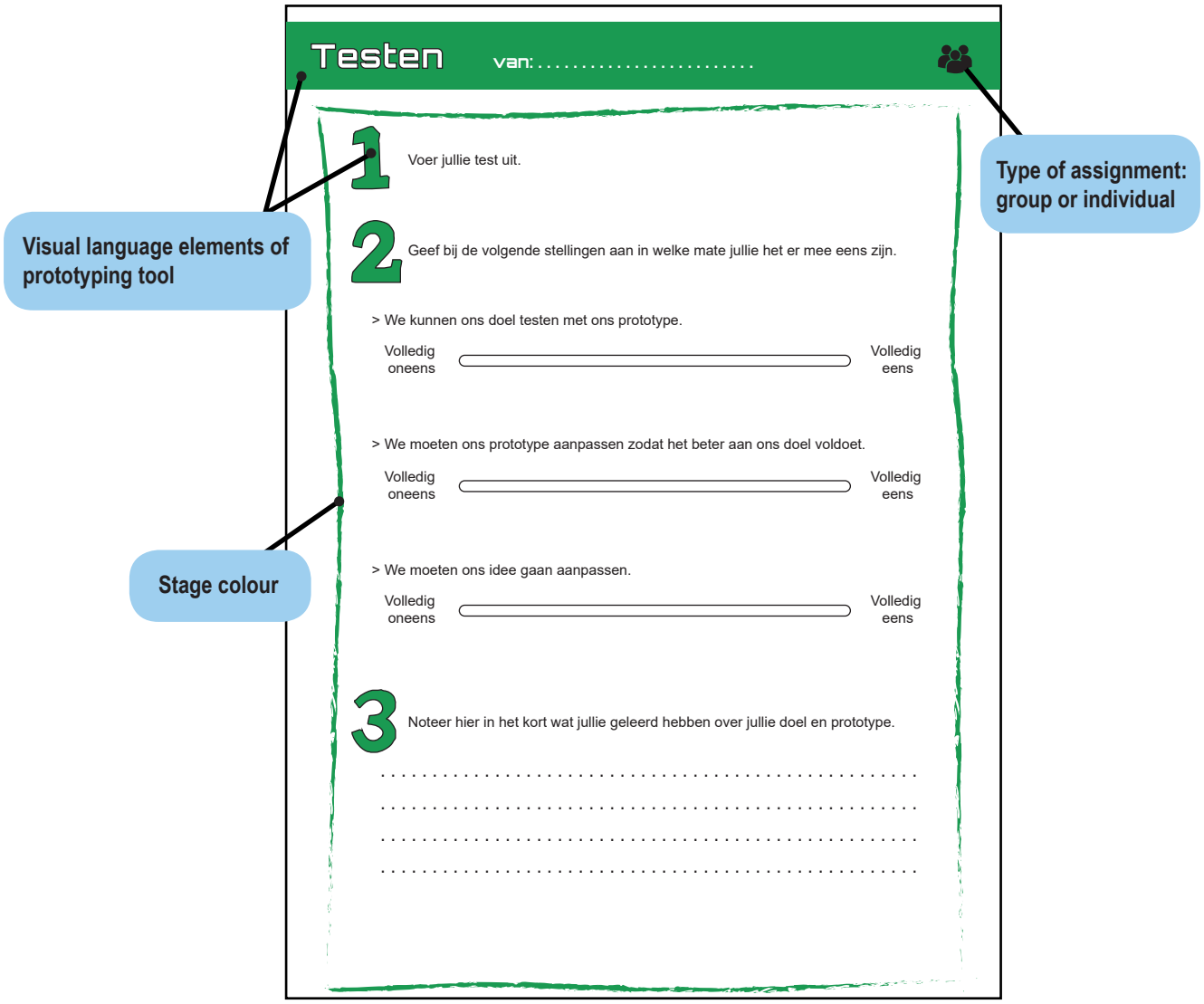


Figure 22. *Recurring elements of the iteration tool*

Goal / New goal

Figure 23 shows the Goal worksheet, the size is A4. The Goal and New goal worksheets are focused on having the children set a goal for their prototype. It is advised to use the Prototype-discussion-game before setting a goal. In order to help children in seeing the link between what they discussed in the game and their own project, the children are asked to make their own goal-card. They can use the goal-cards from the game as inspiration and create their own goal. It is important that the whole group agrees and understands what their set goal implicates. Therefore, the children need to note the things they will and will not make. The idea is that this will lead to less confusion and disagreements in a later stage of the process.
The only difference between the worksheets Goal and New goal is the word 'New' in the heading, the content is exactly the same since the idea is that the children would start a new iteration with the new goal as starting point.

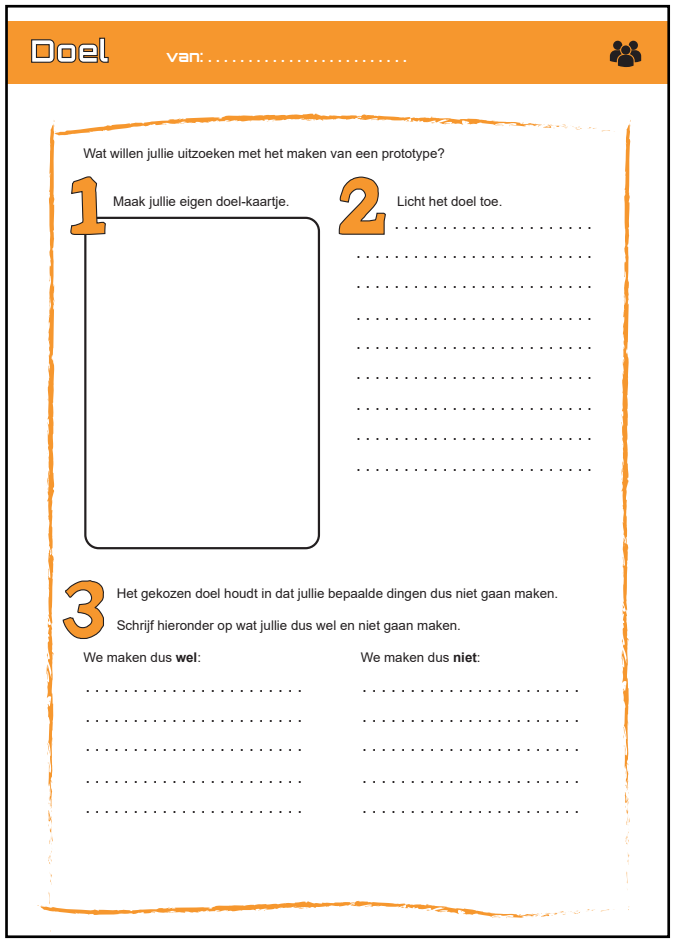


Figure 23. *Goal worksheet*

Plan of Approach

Figure 24 shows the Plan of Approach worksheet, the size is A3. The focus of the Plan of Approach worksheet is on creating a plan so everyone in the group knows what needs to be done and how they can contribute to the process. By creating a plan together before starting to build, the children are forced to make agreements and work together as a team.
After the Goal worksheet the team has a goal for their prototype, but have not yet decided on how to test their goal. Before the children can make a plan of approach they need to decide on how they are going to test their goal. This way they later think of what is needed for the test.
In the first version of this worksheet the children had to write a lot on a form, this would mean only one child could write easily and the rest could be passive. In order to allow all team members to be actively involved, the children are asked to use a SCRUM inspired approach. The children need to write down all the tasks needed to make the prototype and execute the test on post-its. Once all the tasks are written down, they arrange them in order: what needs to be done first and what comes later? Then the children need to write on a different colour post-it how much time each task will cost and what materials are needed for it. Once they are done with this, they can create a table as visualised on the worksheet and divide the tasks. Every time a tasks has been done, the children can actively move there task to the 'Done' column and go on to the next task.

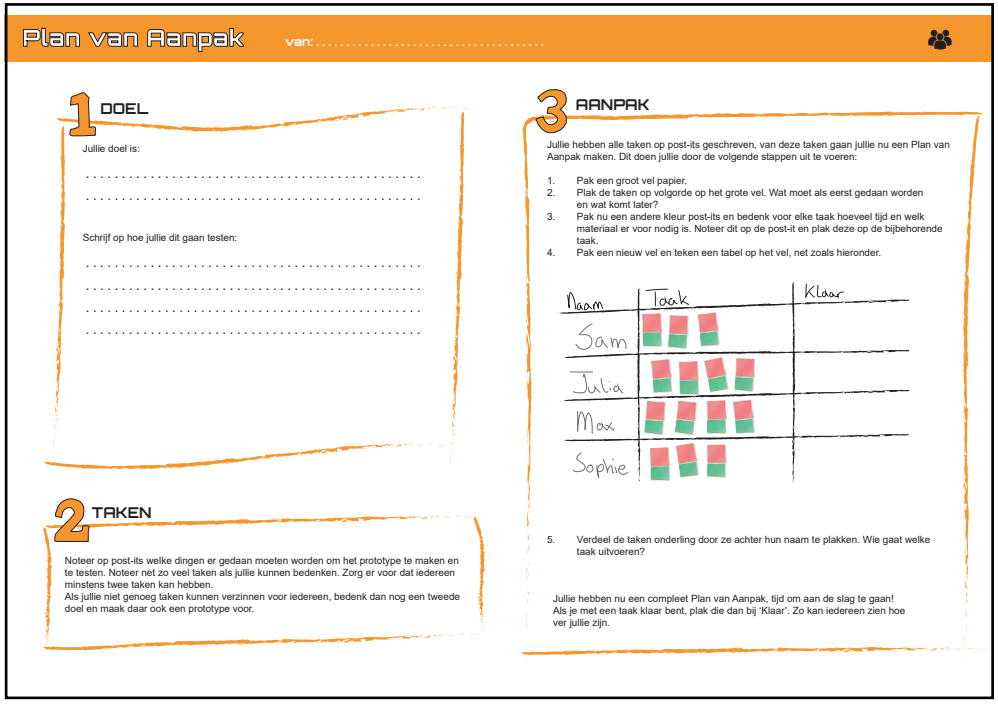


Figure 24. *Plan of Approach worksheet*

Checkpoint

Figure 25 shows the Checkpoint worksheet, the size is A4. While observing children making prototypes it appeared that at the moment children do not know what to do, they start withdrawing themselves from the process. In order to help the children with staying on track there is a checkpoint. With the Checkpoint worksheet the children reflect on their process and plan of approach. It is important that the whole team still knows what to do and works towards the same goal. The worksheet gives the team several reflecting questions to discuss. Once the children have discussed the questions they conclude their discussion by noting agreements on how to proceed. This worksheet uses questions to stimulate discussions to limit the writing assignments. The team still needs to write down conclusions in order to force them to actually think about the questions and reflect on their process.

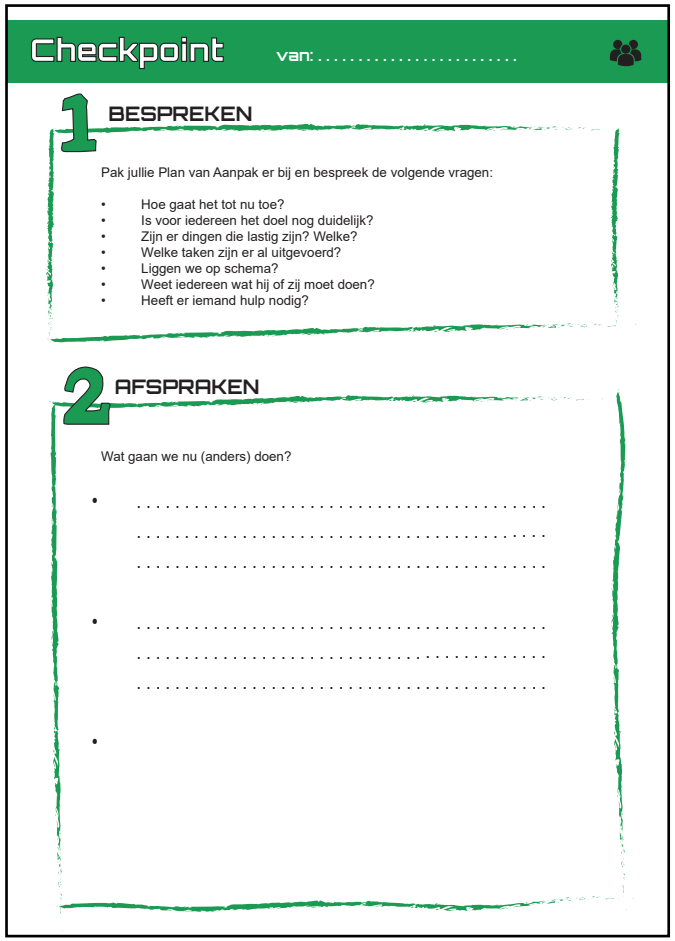


Figure 25. *Checkpoint worksheet*

Test

Figure 26 shows the Test worksheet, the size is A4. After the prototype has been finished, the team can use the Test worksheet. In the first version of this sheet there was no guidance on how to perform the test and the sheet did not give points to focus on. Since performing the test is an important part of purposefully prototyping and children struggle with purposefully prototyping, the sheet has been adjusted to provide more guidance. The worksheet stimulates the children in linking their test to their goal, what their test results mean and how to proceed further. The children are guided through the thinking process by indicating to what extend they agree on three statements and then note what they have learned about their goal and prototype. The statements are stimulating the team to think about their goal.

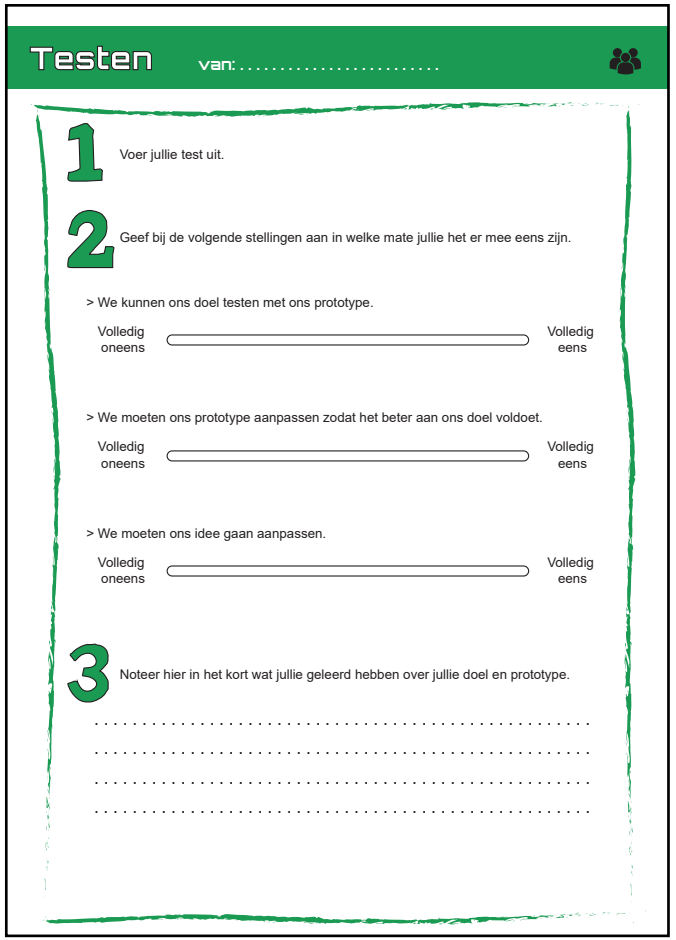


Figure 26. *Test worksheet*

Looking back Worksheet 1

Figure 27 shows the Looking back Worksheet 1, the size is A3. An important part of iterating is learning from what you have done and use that knowledge for your next iteration. Looking back Worksheet 1 focusses on having the teams reflect on what they have done and learn from it. The first version of this worksheet contained open questions asking about what went well and what could go better. After discussing the worksheet with a primary school teacher, she mentioned the questions would be too hard for the children to answer in the intended way. Therefore, the worksheet now consists of some kind of rubric about important aspects of the process the teams should reflect on. The rubric indicates several scenarios and the team can indicate to which part(s) they can relate. By using a rubric the amount of writing required while filling in the worksheets is reduced. In order to force the team to conclude things from their discussion, they are still asked to note two things: what they will do the same a next time and why, and what they would do differently, why and how they would do that.

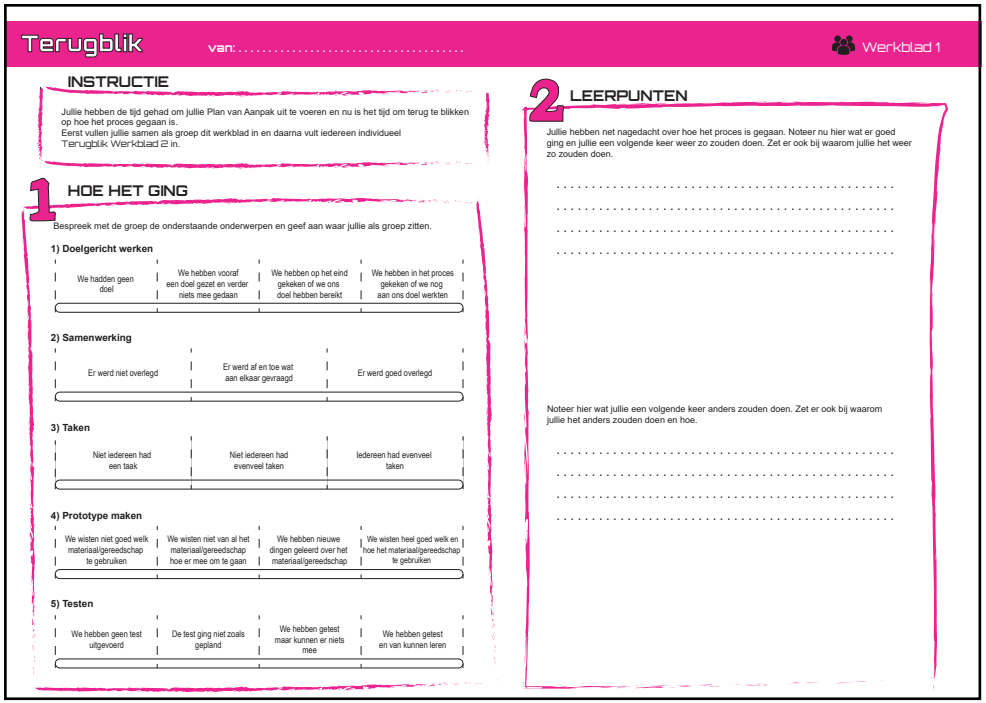


Figure 27. *Looking back Worksheet 1*

Looking back Worksheet 2

Figure 28 shows the Looking back Worksheet 2, the size is A4. Looking back Worksheet 1 is focused on group learning points. Looking back Worksheet 2 is focused on individual learning points. With the Skill tool children learn new making skills. During the iteration cycle they create a prototype and have to use their knowledge and skills for it. With Looking back Worksheet 2 the children reflect on their individual skills and note what they have learned while prototyping and what they would still want to learn to become better in prototyping. The things the children note can help the teacher in preparing new classes and provide and/or facilitate in the knowledge the children seek and need.

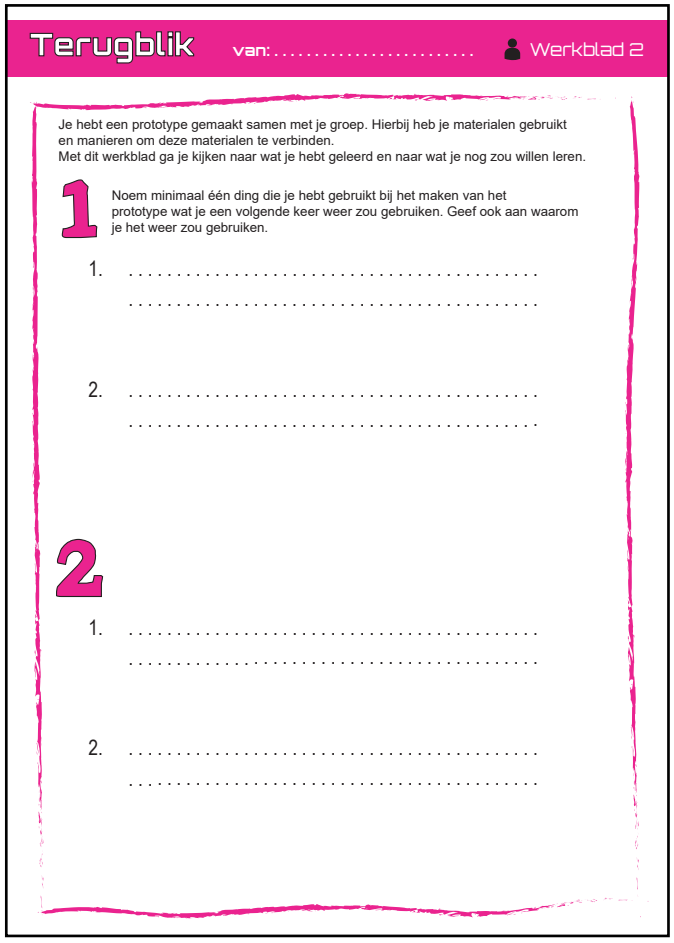


Figure 28. *Looking back Worksheet 2*

Looking back Classroom reflection

Looking back Classroom reflection can replace Looking back Worksheet 1, Looking back Worksheet 2 and Reflection cards. The Looking back Classroom reflection is a powerpoint presentation which consists of statements on six subjects which are similar to the statements on the Looking back Worksheet 1. The difference is that the classroom reflection is done with the whole class and allows the children to learn from the failures and successes of other teams. During the reflection the class is divided in four areas. With each statement the children choose which answer best fits their experience and they stand in the corresponding area. The teacher can ask the children to share their experiences and have the group reflect on situations that occurred during the design process.

Table 2 shows the statements that are part of the Looking back Classroom reflection and Figure 29 shows two slides from the Classroom reflection.

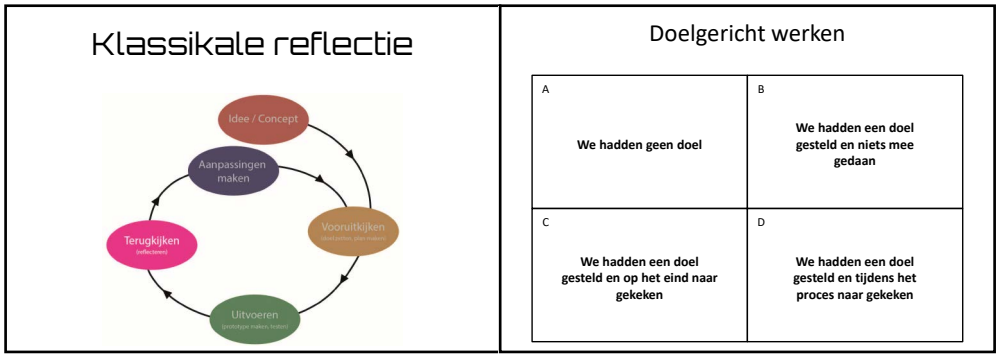


Figure 29. *Two slides of the Classroom reflection*

Doelgericht werken A) We hadden geen doel B) We hadden een doel gesteld en niets mee gedaan C) We hadden een doel gesteld en op het eind naar gekeken D) We hadden een doel gesteld en tijdens het proces naar gekeken	Prototype maken A) We wisten niet goed welk materiaal/gereedschap te gebruiken B) We wisten niet van al het materiaal/gereedschap hoe er mee om te gaan C) We hebben nieuwe dingen geleerd over het materiaal/gereedschap D) We wisten heel goed welk en hoe het materiaal/gereedschap te gebruiken
Samenwerking A) De samenwerking ging goed B) De samenwerking ging niet goed	Testen A) We hebben geen test uitgevoerd B) De test ging niet zoals gepland C) We hebben getest maar kunnen er niets mee D) We hebben getest en van kunnen leren
Taken A) Niet iedereen had een taak B) Niet iedereen had evenveel taken C) Iedereen had evenveel taken	Volgende keer prototypes maken A) Ik zou graag nog nieuwe manieren willen leren voor het maken van prototypes B) Ik hoef geen nieuwe dingen te leren voor het maken van prototypes

Table 2. *Statements of the Looking back Classroom reflection*

Reflection cards

Figure 30 shows the conclusion cards and Figure 31 the statements cards of the Reflection cards, the size of both sheets is A4. The Reflection cards can replace the following worksheets: Checkpoint, Looking back Worksheet 1, Looking back Worksheet 2 and Classroom reflection. There are eight statements for which the team has to indicate if the statement is applicable in that moment of time on their process or not. They fill in the same cards during their checkpoint and after they have tested their goal. By using the same cards at both moments, it allows the team to compare and see the differences throughout their process. After filling in the statement cards, the team needs to conclude their reflection by noting what they will do keep on doing and what they will do differently.

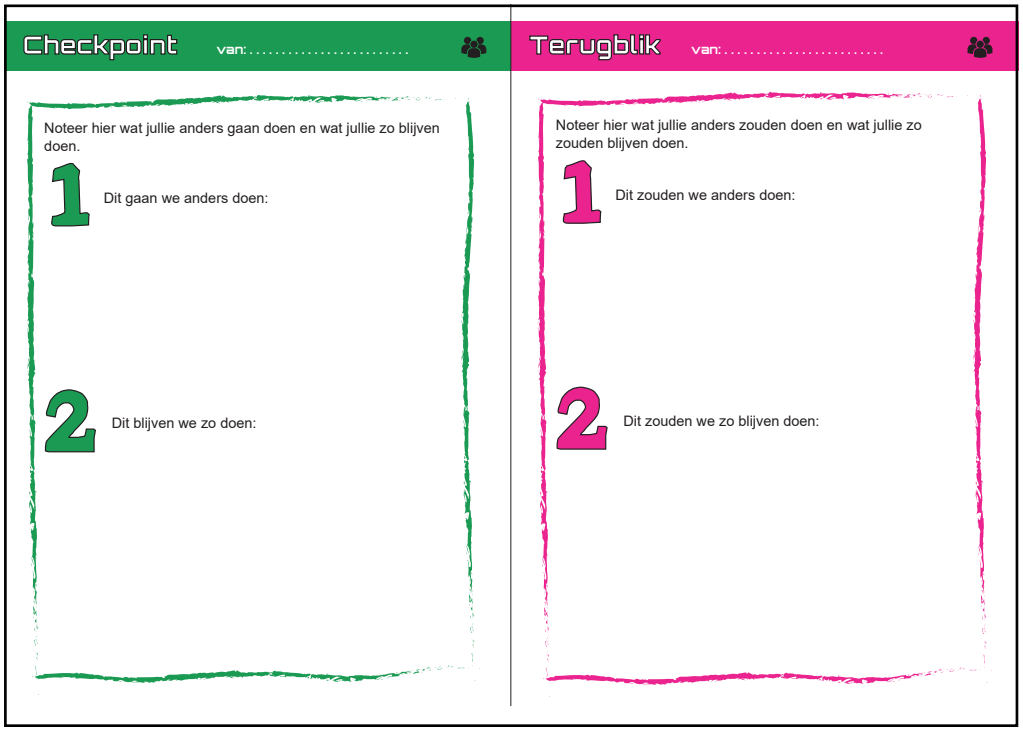


Figure 30. *Conclusion cards of the Reflection cards*

Figure 31. *Statement cards of the Reflection cards*

7.4 Short version

Figure 32 shows the Iteration worksheet of the Short version, the size is A3. The worksheet consists of all the core elements of the iteration model: setting a goal, making a plan, testing the goal, reflecting on the process and determine the next steps. The difference between the Extended version and the Short version is that the Short version does not have a checkpoint and has less reflection questions, so the reflection is less in depth than in the Extended version.

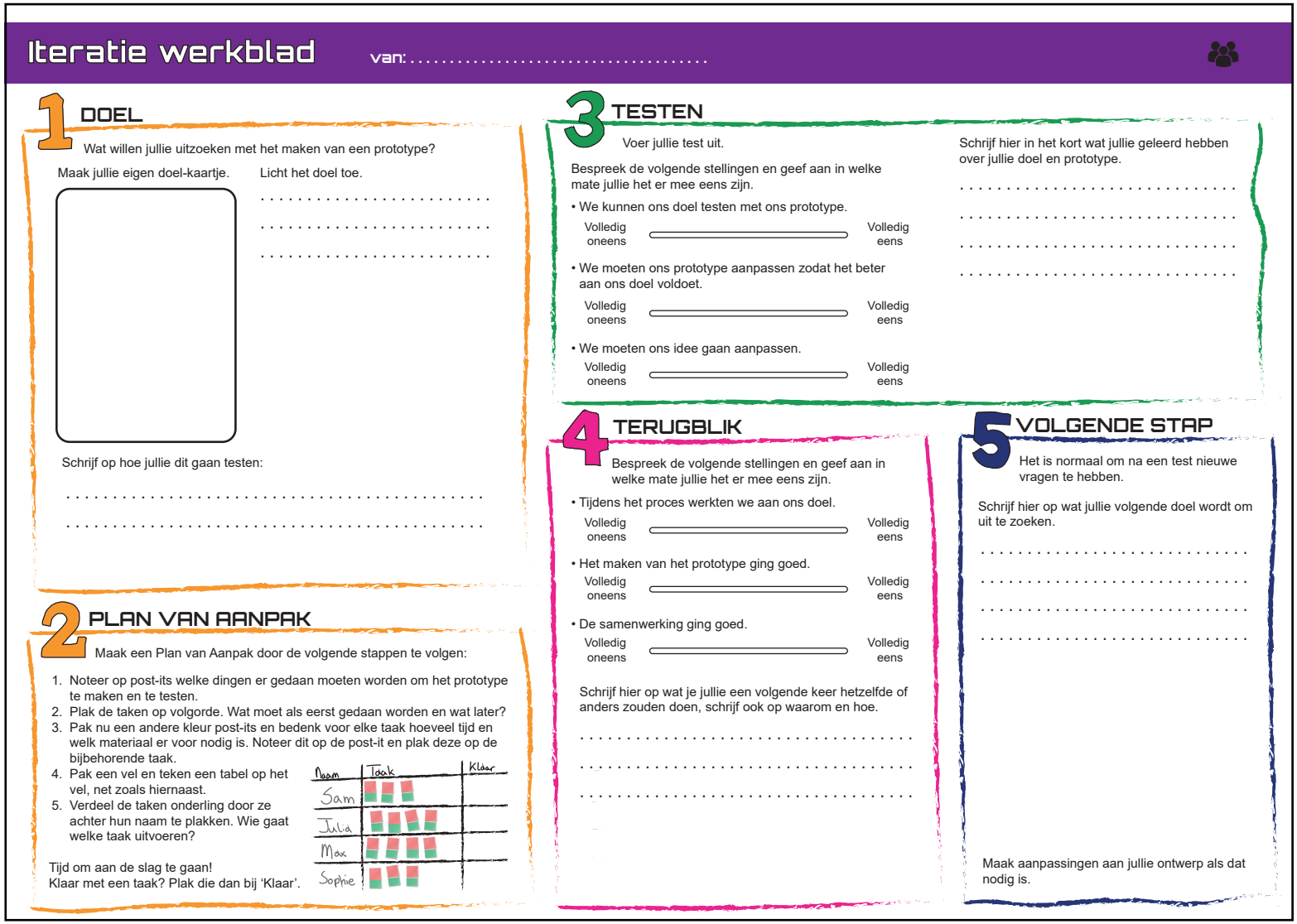


Figure 32. *Iteration worksheet*

8. Info booklet

This chapter describes the different elements of the info booklet for teachers, and why the booklet consists of these elements.

8.1 Information about the design process

When someone wants to help others, it is important that the person helping has the knowledge needed for being able to help. In this project the goal is that teachers help children through the process of using prototyping in a design process. In order to provide the teachers with information about the importance and role of prototyping in a design process, it is important that they also know about the basic elements of a design process. In an interview with a teacher at the PABO (education programme for primary school teachers) it became clear that the design process is part of their education. They learn about the design cycle and clear experiences and thoughts on how to implement parts of the design cycle in their class. The Info booklet shortly repeats the basic elements of a design process in order to freshen up the memory of teachers who just started teaching and make sure teachers that are already teaching for a long time also know and understand the basic elements.
The Info booklet provides the teachers with information about the following subjects: the iterative nature of designing, the design cycle, making prototypes and iterations in a design process.
Figure 33 gives a representation of the pages of the Info booklet providing information to the teachers. The full Info booklet can be found in Appendix 7.

8.2 Tips

Next to providing the teachers with information about the design process and the role of prototyping, the Info booklet also provides some tips for preparing a design assignment and coaching teams in a design assignment. The tips are focussed on prototyping in a design process, since the scope of this project is prototyping in a design process.
When teachers read the tips and have additional tips that can be valuable for other teachers, the booklet invites them to share their tips with Science Hub TU Delft. This way the booklet can be complemented and provides the best tips to support teachers in coaching children through the process related to prototyping.

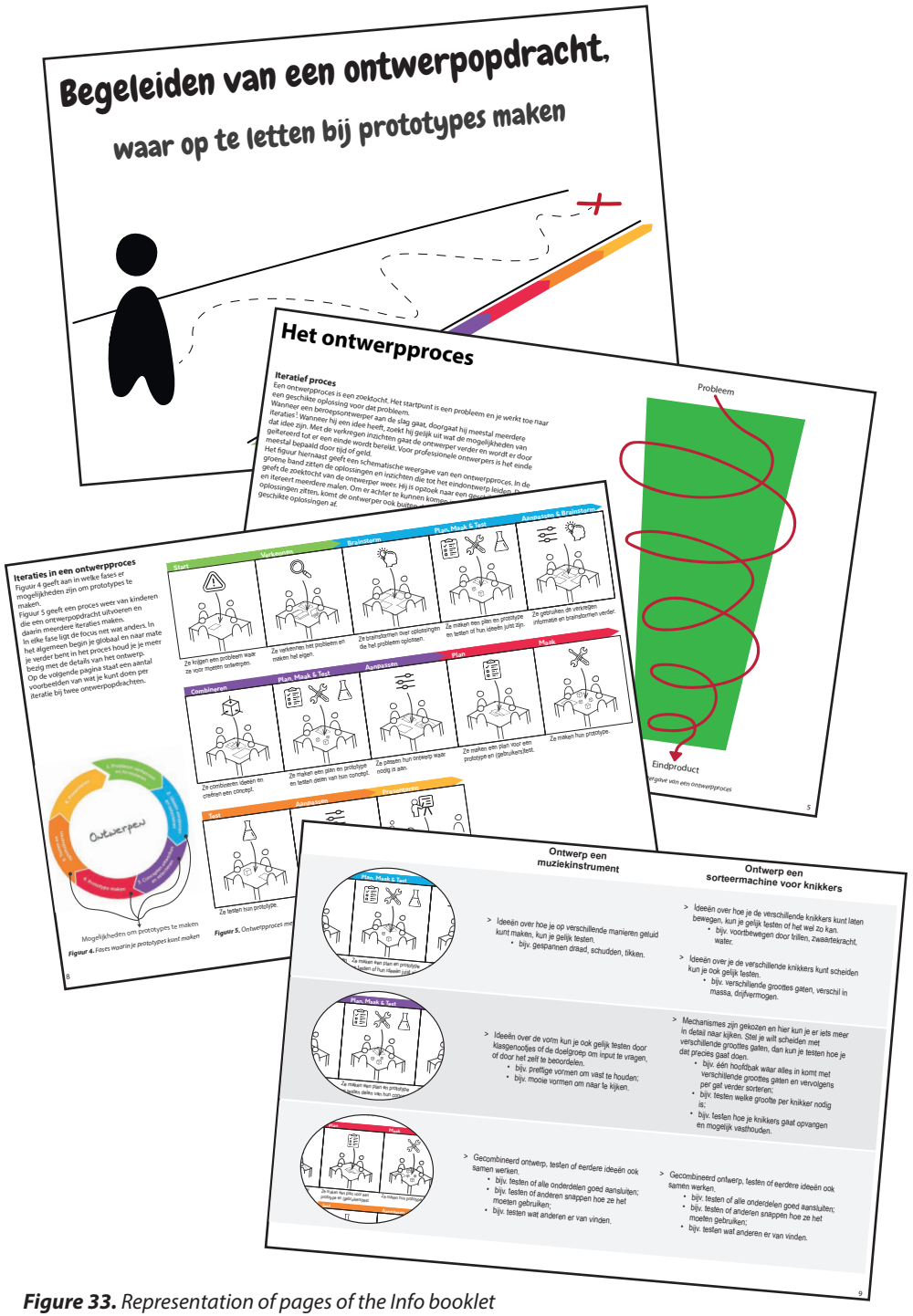


Figure 33. *Representation of pages of the Info booklet*

9. Tests

The aim of this project is to get children to better utilise making prototypes in their design process and two design goals are set to achieve this, one that involves the children and one that involves the teachers (see chapter 3).
Several tools are developed to achieve the design goals of this project. The tools are tested and this chapter describes the test set up of each tool.
Due to COVID-19 all tests are performed without the researcher present and at home instead of at school.

9.1 Skill tool

This section describes the goal of the test of the Skill tool and the test set up.

Goal

The main question whether the Skill has a positive influence on the quality of prototypes children make in a design project, is a question that cannot be tested in the current situation because the schools are closed. Therefore, the goal of this test is to find an answer to the following research questions:

1.1 How do the children experience using the Skill tool?
1.2 Are children able to follow the step by step instructions explaining the skill and execute them?
1.3 Are children able to execute the last step and apply the knowledge they just gained?
1.4 Are the selected skills relevant and in line with the cognitive and motor skills of the children?

Answers to these research questions give insight on the core of the Skill tool: Learning a skill via instructions and applying it in a different context.

Test set up

In order to find an answer to the research questions and receive feedback, the Skill tool is tested in two ways.

1) Children using Skill tool

Who: 2 boys, 9 and 11 years old. The youngest is in group 6 and the oldest in group 8 (last year of primary school).

Where: At home

What: The children are asked to choose two forms and execute the steps. In order to get a feeling of what the children do, they take pictures of the things they make. After executing the steps they are interviewed.

How: The children receive the DIY-instructions digitally and can either follow the instructions on a screen or print the instructions. For the execution they use the materials they have available at home.

2) Experts on making review the skill set

Who: Maker with experience in creating materials for children and 6 fellow designers.

What: The maker is asked to give feedback on the Skill tool as a whole, so on both the design of the forms and the content. The designers are asked about important skills needed when you want to make a prototype.

How: The maker receives the Skill tool via mail and provides it with feedback via mail. The designers do a small online brainstorm on making skills.

9.2 Prototype-discussion-game and Iteration tool

This section describes the goal and test set up of the test of the Prototype-discussion-game and the Iteration tool. Before these elements are tested, two boys of 11 years old (group 7 and group 8) reviewed the materials.

Review of test materials

Goal

The goal of the review before testing the Prototype-discussion-game and Iteration tool in a design assignment, is to already have a more fitting and clear set of forms that are understood by children in the target group.

Test set up

Who: 2 boys of 11 years old. One is in group 7 and one in group 8. The one in group 8 also tested the Skill tool.

What: The children give their opinion on all the elements of the Prototype-discussion-game and Iteration tool.

How: The children read the materials and in an online interview they give their opinion on all the different elements. They give feedback on the design and content, meaning whether they understand what is asked from them.

Results and changes

1) Prototype-discussion-game

One of the boys mentioned that the instructions of the game were not complete. It is missing what you have to do with the not chosen goal-cards. Therefore, a line about what to do with those cards is added to the instructions.

2) Test worksheet

One of the boys mentioned that the statements on the Test worksheet are clear, but that the phrase "volledig (on) eens" is not clear in its meaning. In order to make it better understandable in Dutch, the word "mee" is added to the phrase, creating "volledig mee (on)eens". The Iteration worksheet will not be tested, but also has the phrases on it so these are also updated based on the feedback of the child.

3) Looking back worksheet 1

Both boys mentioned that the Looking back worksheet 1 looks very complicated to fill in. In order to make it more clear the strange scale is changed into tick boxes (see Figure 34). Both boys mentioned that with this adjustment the worksheet does not look very complicated anymore, and is clear.

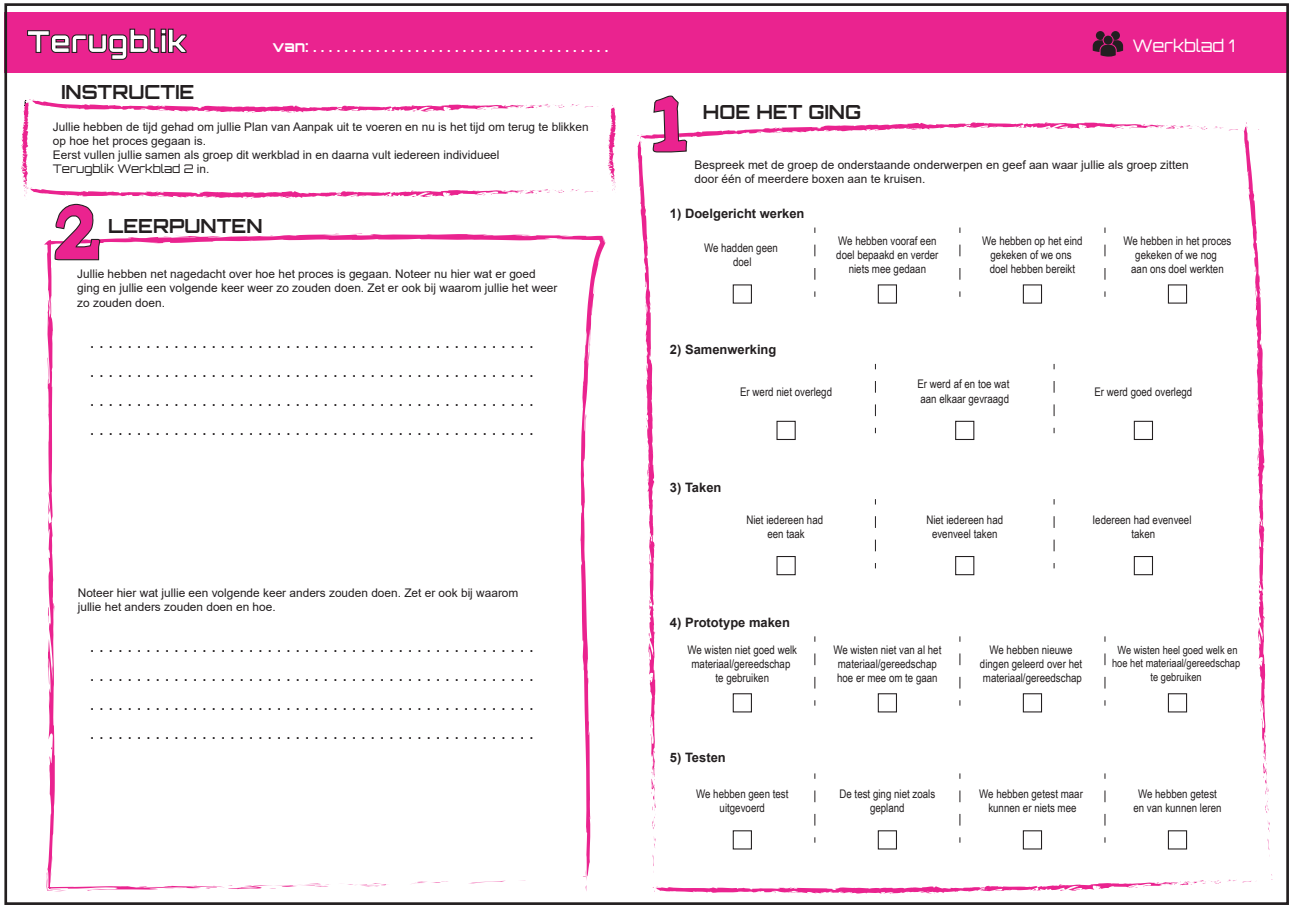


Figure 34. *Looking back worksheet 1 with tick boxes*

Goal

The goal of this test is to find answers to the following research question:

2.1 How do the children play the Prototype-discussion-game?
2.2 Do the children understand the worksheets?
2.3 Are the children purposefully prototyping?
2.4 Are the children able to reflect on what they do?
2.5 Is their new goal related to the test results? (Do they iterate?)
2.6 How do they experience using the Iteration tool?

Test set up

Who:

1	C1: Boy 9 years, group 5	C2: Boy 7 years, group 4	Siblings
2	C3: Girl 9 years, group 6	C4: Boy 7 years, group 3	Siblings
3	C5: Boy 11 years, group 7	C6: Girl 9 years, group 5	Siblings
4	C7: Boy 11 years, group 8	C8: Boy 13 years, class 1	Siblings
5	C9: Boy 9 years, group 5	C:10 Girl 7 years, group 4	Siblings
6	C11: Girl 9 years, group 5	*H7: Dad	Daughter & father
7	C12: Boy 10 years, group 6	C13: Boy 14 years, class 3	Siblings
8	C14: Boy 11 years, group 8	C15: Boy 11 years, group 8	Friends
9	C16: Girl 10 years, group 7		
10	**C17: Girl 10 years, group 6	(C18: Boy 5 years, group 2)	(Siblings)

C = child, H = helper
* This helper executed the assignment together with his daughter
** After the game she continued without C18

Table 3. *Participants of the Prototype-discussion-game and Iteration tool test*

Where: At home

What: The children are asked to do a design assignment (design protection for an egg so it does not break when you let it fall from 2 meters) by using the materials of the Prototype-discussion-game and Iteration tool (Goal, Plan of Approach, Checkpoint, Test, Looking back worksheet 1 and New goal). The tool is slightly adjusted to consume less time. The Checkpoint worksheet has less questions that need to be discussed and the Looking back Worksheet 2 is left out. The total time the test will take is estimated on 2,5 hours.
After they finished the assignment they are interviewed.
Appendix 5 shows the instructions for the parents and children that participate in the research.

How: The children receive a package with all the materials (game elements and worksheets) they need to execute the assignment (see Figure 35). For making the prototype they use the materials they have available at home. They will record their session(s).

Figure 35. *Package for a test family*

9.3 Teacher tool

This section describes the goal of the test of the Info booklet and the test set up.

Goal

The goal of this test is to find out whether teachers understand the info booklet and think it is valuable. The test should give answers to the following research questions:

3.1 Do teachers understand the booklet?
3.2 What do teachers think of the booklet?

Test set up

Who: 2 primary school teachers with experience in teaching in group 5 and 6.

What: The teachers are asked to read the Info booklet and provide it with feedback.

How: The teachers receive the booklet and the questions digitally and can either respond digitally or answer the questions in an interview.

10. Results & conclusions

In this chapter the results of the tests are presented and conclusions are drawn. First it describes the results and conclusions of the Skill tool test, then the Prototype-discussion-game and Iteration tool test and lastly the Info booklet test. All the quotes are translated to English.

10.1 Skill tool reviewed by children

The two participants had a different experience while using the Skill tool.

Participant 1

Boy
11 years, group 8

Experience with making/designing
Participant 1 has experience with needing to create something, e.g. a scale treehouse, that needs to meet some requirements.

Chosen skills
Participant 1 chose to execute the following skills, since that were the only things he had available at home: Connecting cardboard using tape + Connecting cardboard using glue.

> *" Only things we had at home. "*

Appearance of the tool
The appearance looks thought through.

> *" The way they made this is nice. "*

> *" It has a goal. It is not a toddler who thought 'Oh yes, I am going to make this. "*

Executing the steps
For participant 1 executing the steps was easy. For choosing what to make in the last step he looked at what he just made and thought by himself, "what does this remind me of?" He made what he thought of. Figure 36 shows the creations of participant 1.

> *" I just went in the garden, placed everything I need on the table, cut, glued. "*

> *" I was just thinking, what does this look like? And it reminded me of a tree. "*

> *" I have not done it like this before. "*

Figure 36. *Creations of participant 1*

Extra skills
Participant 1 mentioned that he would like to learn soldering.

Instruction video
Participant 1 prefers text over an instruction video, because it allows you to go through it on your own pace.

“ Then you can first look at it and after that go through all the steps. Instead of having to watch the movie several times. And you can watch it on your own pace. ”

Participant 2

Boy
9 years, group 6

Experience with making/designing
Participant 2 has experience with making and designing. He attends a skill group at school.

Chosen skills
Participant 2 chose to execute the following skills because they were new to him:
Creating a hinge using paper clips and straws + Deforming iron wire

“ I do not really like cardboard. So I thought, this looks fun to me! ”

Appearance of the tool
All the elements on the cards are clear to the participant.

“ Nice, especially the design of the materials. ”

Executing the steps
The experience participant 2 had with the Skill tool differs per skill and part of the execution.
Creating a hinge using paper clips and straws:

Executing the DIY-instructions was easy. Executing last step was difficult. It was hard to think of something to make.

“ I do not know what to make with the skills you just learned. ”

Deforming iron wire:

Executing the DIY-instructions was quite frustrating. It was not clear to him how to execute the steps. It was a new tool and he did not know how to use it. The last step was easier with extra guidance (see Figure 38).

Figure 37. *Creation of skill card one and execution of skill card two of participant 2*

Instruction video
He prefers the instructions on paper. This way you do not have to pause the movie all the time.

> *“ More pleasant, because then you do not have to pause, start, pause, start. ”*

Iteration within the test

Participant 2 struggled with executing the last step on the instruction form. Therefore, the last step was adjusted according to his feedback and the approach of participant 1. Figure 38 shows the adjusted last step which participant 2 used while executing his second instruction form (deforming iron wire).

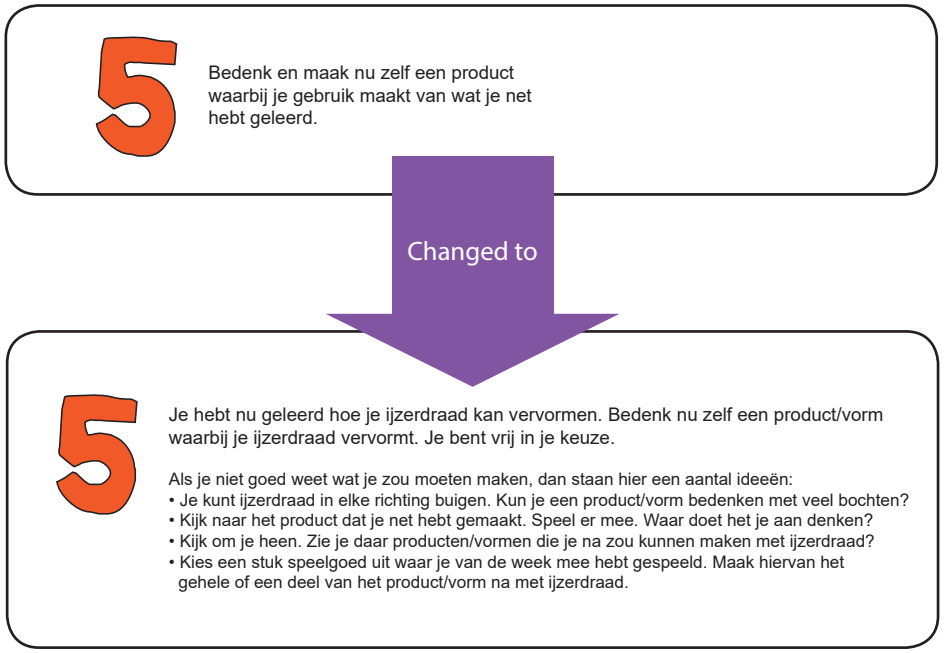


Figure 38. *Adjustment within the test*

Participant 2 has used the adjusted last step when executing his second instruction form and he said that the adjustment helped him in coming up with something to make.

Conclusions

Using the Skill tool
Both participants liked using the skill cards. For one of the participants is was very easy to perform all the steps, but the other participant was struggling with the last step on the form: creating something new with the skill he just learned. The intervention of elaborating the last step (see Figure 38) made it easier to come up with something to create.

Type and level of the skills
All the skills cards chosen by the participants were new to them. ‘Deforming iron wire’ was difficult to execute because the steps were not guiding enough in how to handle the pliers. Using pliers is something completely new to the children, so they need more guidance in how to hold and use it, in order to execute the steps without lots of frustration. It could be that the frustration stays even when the steps are more clear. This is something that has to be tested.
When children learn a new skill, the skill card should provide visual information of how to execute a step and how to handle the tools.
Four out of eight skill cards are tested, the other four still need to be executed by children before you can draw conclusions for those cards.

Form and design of the skill cards
Both participants liked the form of the skill cards. They prefer text and images over an instruction video. The physical card gives them autonomy and freedom in how they can use it. The cards allow them to go through the skill on their own pace, without having to struggle with starting and stopping a video.

The design does not look childish and invites the children to use the cards.

10.2 Skill tool reviewed by experts

Images

The scale of the images changes and that can be confusing.

> *“ Make sure that all the images on one sheet have the same scale, or that the context shows the scale. ”*

Goal

At the moment the goal/end result of the skill card is only explained in text.

> *“ Make sure that you know why you have this worksheet. Explain at the start what you can do with it. ‘With this connection you can ... (with image)’. ”*

Last step

The purpose of the last step is unclear.

> *“ I would leave out the last step (then it is just instructions) or I would elaborate on it more so it becomes a clear assignment and is clear in why you should do it. ”*

Conclusions

Design of the skill cards

It is important that there no confusion about how to execute steps because of a changing scale in the used images. It is better if the images use the same scale or if the context implies the scale.

It is also valuable if the skill card immediately shows what the end result would be. This allows the children to directly read and see what they could learn via that skill card.

Last step

Before the adjustment to the last step it was unclear what the precise assignment and goal was.

Selection of skills

Figure 39 shows the outcome of the brainstorm on needed making skills for children. Multiple designers mentioned that a needed skill for making prototypes is knowing how to combine and connect elements. They also mentioned the properties of materials as something interesting for children to be aware of when prototyping.

Conclusions

The selection of skills would be more complete if it also involves the materials paper and cardboard rolls (empty toilet rolls) and soldering. Paper and cardboard rolls are materials that are cheap and easy accessible. By involving cardboard and paper in the skill selection, children could also learn about the properties of different materials. There are a lot of actions you can both do with cardboard and paper, but the properties of your prototype will differ.

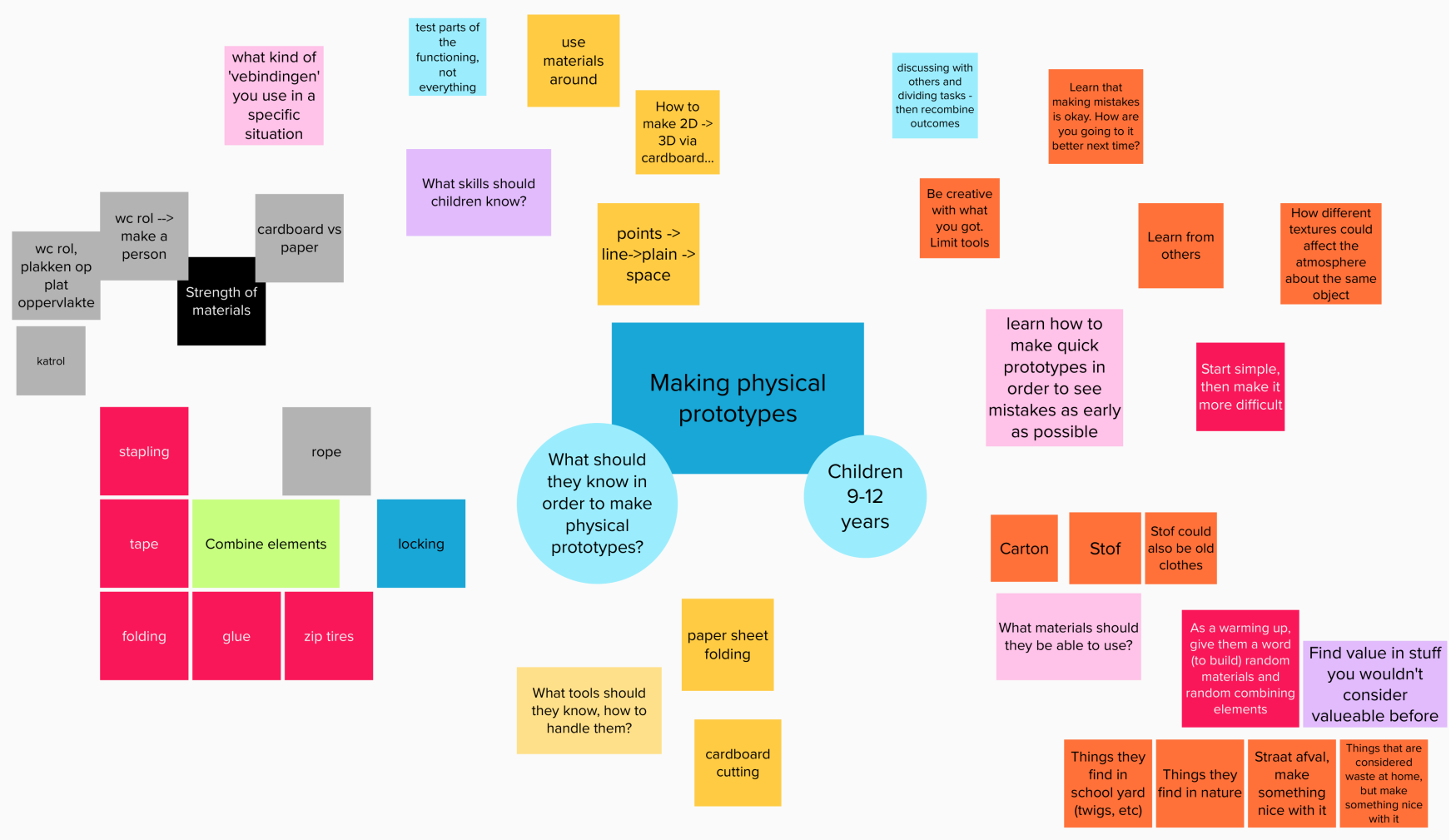


Figure 39. *Brainstorm on making skills with designers*

10.3 Prototype-discussion-game

In this section the results and conclusions of the test of the Prototype-discussion-game are presented. The overall approach is to first present the common denominator and then present less common but still interesting findings.

Playing the game

8 out of 10 groups were able to play the game and used the playing field in a way that made sense to them. Some place the A3 sheets next to each other, with the area for the pairs in the middle. Others place the sheets next to each other with the area for the pairs on the edges. And some only used one sheet as game area. Figure 40 shows a few different ways the playing field was used.

Figure 40. *Participants playing the game*

2 out of 10 groups were not able to play the game. One group did not understand what were supposed to be the goal-cards (the goal- and prototype-cards were not present when they tried to play the game). For the other group it was not clear how to use the playing area. In the interview one of the children from this group mentioned that they did not look at all the materials. When he saw both parts of the playing field he mentioned it made more sense and that he, at that moment, understood what they were supposed to do. During the test he had not looked at the second part of the playing field.

All the children that played the game liked playing the game and would want to play it again. Below you can find a few quotes from the interviews that represent what the children thought about playing the game.

> *“ C4: The game of 15 minutes I did like.*
>
> *H3: Oh yes, with those cards.*
>
> *C4: Yes, that was really fun. ”*

> *“ R1: What did you think of playing the game?*
>
> *C5: That was really fun.*
>
> *C6: Yes, that was nice. ”*

> *“ C11: Yes, I really like to play it again. ”*

Conclusions

The game area and how to use it, is not completely clear to most groups. All the groups that have started the game did find a way of using the game area that works for them. The green prototype-goals area was used to make pairs.
When the explanation and materials available are not fully looked at it is hard to understand how the game is supposed to work, so it is important that children take and get the time to go through the explanation and materials calmly.

The game is a nice change of pace and was fun to do for children. All the children that played the game would like to play the game again.

Discussing

The game is played in different ways.
In most groups the children gave an argument for their choice. Below you can find a few arguments the children made.

" C16: With this prototype you can test whether it looks attractive, because, if it for example really doesn't look nice, then you could also just have an extra bag instead of it being connected to your sweater. Therefore I think it should look nice. "

" C11: Because if it doesn't work, why would you buy it. "

In some groups there was a small discussion once in a while about the chosen goal-cards. Below you can find an example.

" H8: I can imagine most important is whether the parts fit.

C12: Really?

H8: Yes, otherwise you can't use it, then it falls apart.

(C13 says something inaudible)

C13: But mine is also true because it has to work. Can it go like this?

H8: I think this one is better formulated than yours.

C13: But I couldn't formulate is differently. "

In other groups the children were often in agreement about which goal-card fitted best with the prototype-card.

" C5: I think we should go for this one (points at own card). If it works, you can only place your phone on it, so I think it will work. I think the question to answer would be whether people would buy it. I think this fits better. What do you think?

C6: Uhh, yes. "

In one group there was no discussion about the chosen goal-cards. This group just placed the goal-cards on top of each other as a prototype-goal pair.

A different approach

There was one group that took a bit of a different approach. In this group the children took turns in matching a goal-card to the prototype-card. This group also elaborately talked about what they saw on the prototype-card.

" C17: Alright, I see a box and a knife. And it cuts something. I also see a piece of rope here, so I think that when you pull that rope, the knife goes through what you want to cut.

And, I don't know why there is a box, maybe.

H12: And there is styrofoam.

C17: Yes, styrofoam. Oh! Maybe this small box (points at image) is used by placing your foot on it and that the rope goes down and the knife cuts. Cuts it. I think.

H12: And what would be the goal? Of this prototype.

C17: Uhm..

C18: This? With this..

C17: Maybe whether it works?

H12: Yes, that's what I thought too. I think it's a good one.

C17: Alright. "

Conclusions

One of the goals of the game is to facilitate in a discussion between the children about what they think. There was not that much discussion about the chosen cards. They did come to agreements of which card fits best. Most children were able to give arguments for their choices and used what they saw on the images as references.
When talking about the goal-cards the children talked about the possibility of testing the goal with the prototype on the prototype-card.

Influence of parents

The children played the game together with or in presence of their parents. Parents often took the lead in the discussion. Here you can read two fragments of the test of two different groups.

" C9: With this prototype you can test whether it is safe in use.

H6: And why do you think so?

*C9: When it is really, loose, then *tjiek* (makes cutting movement with his hand).*

H6: Yes, that's true.

C9: And what do you have C10?

C10: I have, with this prootype you can test whether it is strong enough. Because if the bicycle falls apart, then you can't use it anymore.

H6: Yes, that's true.

C10: And then you have spent your money for nothing,

H6: And which one do you think fits best? That you use it to test whether it is strong enough, or whether it is safe in use?

C9: Strong.

H6: Then we use that one, that can go there (points at place for goal-card). "

" H2: Yes, take a look at it. Why would this one be good for testing whether the sizes are right?

C2: Well, because you need rulers to measure how big it is.

H2: Yes okay, but why would this prototype, look at the image. Why would this be a device to test whether something fits? When you look at the image.

C1: Well, you need to make it at the right height. Because if you for example have a small one, for example this much (indicates a distance with hands) and you want to place an iPad, which are sometime this big (indicated greater distance), then it doesn't fit.

H2: So I think you both picked a really good one, I really think so. "

Conclusions

Parents influence the discussion of the children. In some groups the parents only facilitated the discussion by asking the children what they think in order to make sure everyone got to share their thoughts. In other cases the parents directed the children through their thinking process.

No winner

A few children had to be reminded that the game was not about who's card would be picked, but about which card fits best. Once they were reminded of this their attitude towards the cards changed. Below you can read two fragments of two different groups were the attitude of the children shifts.

" H1: Yes, alright. Which fits best? Which do you think fits best?

C2: This one (points at own card).

C1: Really?

H1: Yes, when you hear both? It is not about winning, because it is just in the middle now.

C2: Well, then I choose the one of C1.

H1: That you look whether it fits?

(C2 nods)

C1: I would choose that one too. "

" C9: I would pick mine.

C10: I mine.

H6: You really need to choose together the one that fits best. You can also discuss which fits best and why.

C10: I think the one of C9 is slightly better.

C9: If people want to buy it, then you also know that the proportions are good which is your card. Then you know you made it well. That's why I think my card is good.

C10: Yes, I also think yours is good and that it belongs to it. "

Conclusions

Playing the Prototype-discussion-game is experienced as playing a game and in most games there is a winner, but not in this game. It is important to remind the children that there is not a winner or loser in order for them to be objectively towards the different goal options.

Learning from playing the game

Two groups explicitly mentioned that they used the goal-cards of the game as inspiration while trying to create the goal for their own prototype.

> *“ H7: It was hard to think of a goal.*
>
> *C11: Uhuh.*
>
> *H7: We quickly went to the goals on the goal-cards of the game. ”*

One child mentioned that by playing the game he learned that all products you can buy, have had a prototype to test whether the product can be sold and/or is safe.

> *“ C5: Everything you buy, for example household products or a car. Everything had a prototype before you can really use it. To know for sure that it for example good or safe. ”*

Conclusions

Playing the game is educational. It makes children aware of different goals prototypes can have. When a group struggles with setting a goal for their prototype the goal-cards are inspirational.

10.4 Iteration tool

In this section the results and conclusions of the test of the Iteration tool are presented. The overall approach is to first present the common denominator and then present less common but still interesting findings.

Executing the assignment by using the worksheets

9 out of 10 groups were able to use and fill in all the worksheets in the intended order. There was only one group that was not able to use all the worksheets in the intended way. This group executed the assignment without the presence of their parents. Table 4 shows which worksheets they did and did not use. The reason they gave was that they did not make a prototype, but just created their idea.

Worksheet	Used?
Goal	Yes
Plan of approach	Partly
Checkpoint	No
Test	No
Looking back	Yes
New goal	No

Table 4. *Use of worksheets by C7 and C8*

This group was also already building their "prototype" before they used the goal worksheet. They lost track of what to do and in which order because of the amount of worksheets. Below you can find a quote about it from the interview.

" *C7: Well, it was not too much effort. It's more that there are too many sheets.*

R1: Alright, so too many sheets which made it unclear?

C7: Yes, because you think did I already do this, or not? "

During the interview this group saw the Iteration worksheet and said that it would have been clear and helped them to do what they were supposed to do.

Conclusions

When there is an helper present groups are able to use the worksheets in the intended way. Filling in the worksheets only makes sense when you create a prototype.
When using the Iteration tool for the first time it is hard for children to keep an overview because of all the different worksheets.

Filling in the worksheets

In the groups where children were ≤7 years old, the parents had to help them more than the older children with filling in the sheets.

A few groups (children or parents) mentioned that filling in the worksheets was out of proportion with the time that was needed for executing the assignment. For some filling in the worksheets took long compared to the time spent on making a prototype. For others filling in only took a short time and it became annoying that it were so many worksheets. Below you can find a quote about filling in the worksheets from an interview.

" *C14: There were so many worksheets and every time it only takes a short while to fill in. So you take a worksheet, fill it in and put it away again.* "

Conclusions

For the younger children (7 years) it is harder to understand and fill in the worksheets. It is harder to understand the reasoning behind filling it in. The urge to just start building is higher for the younger children, but still also present with most older children. Even though the worksheets are harder for younger children, they still manage to use them (with help from their parents).

Creating a plan of approach takes some time, but once a group has a plan they can quickly build their prototype.

Goal worksheet

Figure 41 shows a few Goal worksheets of the participants. Some groups filled in all the steps and some only filled in part of the sheet.

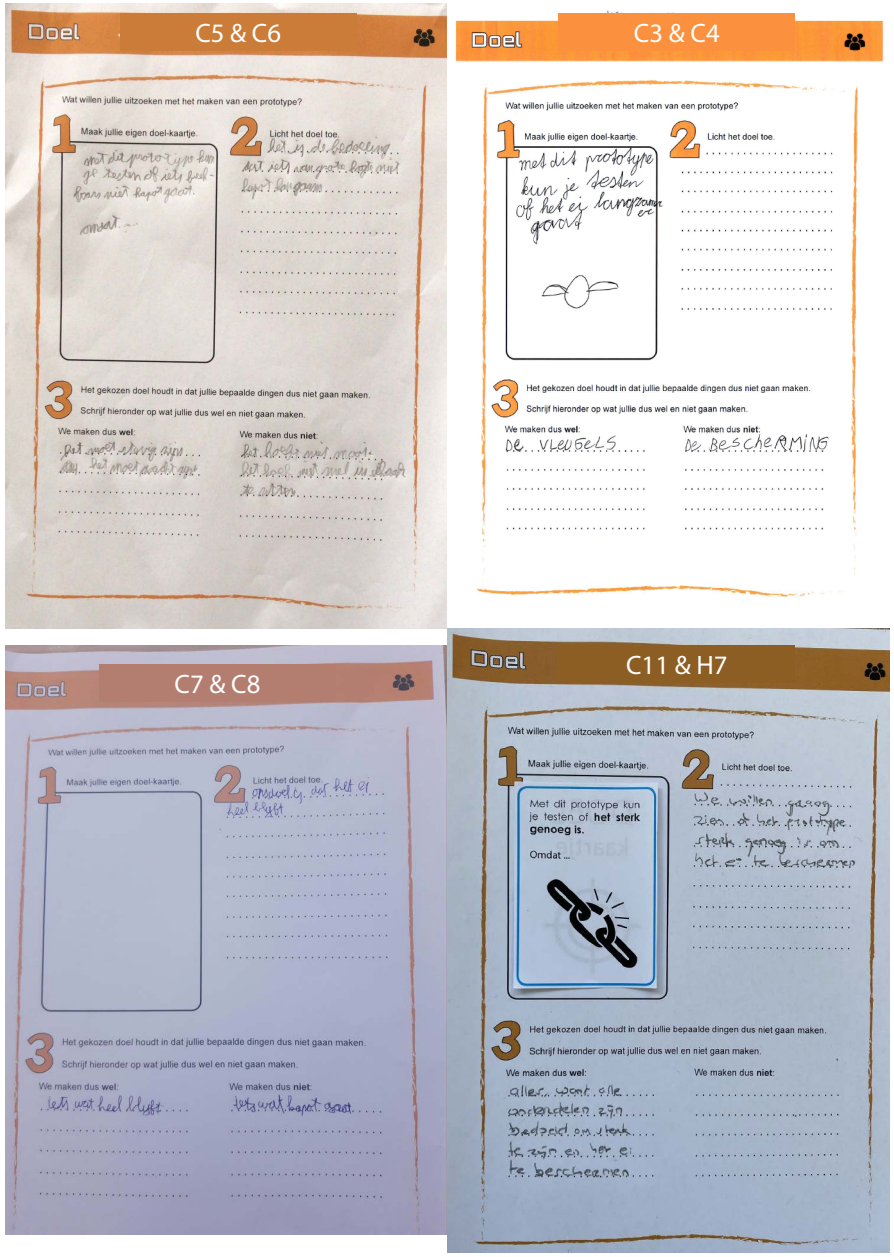


Figure 41. *Goal worksheets of some groups*

Some groups that did not fill step 2 mentioned that for them step 1 and 2 were the same, so they did not know what to write at step 2 after already having done step 1.

Conclusions

Step 1 and 2 of the (new) Goal worksheet are very similar in the eyes of children and parents. The groups that did fill something in mainly copied what they said at step 1, so step 2 does not add value to the goal worksheet.

Looking back worksheet

When filling in the Looking back worksheet only a few started on the right with step 1. Most started on the left and did not notice the numbers of the steps. At least two groups did notice the numbers and one group started with 1 because he did not have to write anything there.

Conclusions

Children are used to working from left to right and when all the worksheet use the same order except for one, children will not notice the additional guiding elements and will fill in the worksheet starting on the left.

Working purposefully

Using worksheets

Several groups (parents or children) mentioned that using the worksheets helped them in working in a structured way and that it forces the children to think about what they are doing.

Below you can read a quote from the interview with C5 and C6. C6 directly knows she wants to use the worksheets again because it helps her remember things. And while talking C5 comes to the conclusion, through his own arguments, that he would also use the worksheets again because they are useful.

" R1: Would you use the worksheets again?

C5: I'm not sure. I think I could also do it without the sheets.

R1: Okay, and C6?

C6: Yes, I would use the worksheets again.

C5: It is useful that you can write down the information and also which materials. For example writing down which materials you need to use. If you forget, you forget a piece of material and then for example it doesn't work. And then you think, I have to do it again while it might have worked if you would have used the material you forgot.

R1: Okay, tell me if I summarize it well. You would like to do it without the worksheets, but it is easier to use them to make sure you don't forget a step?

C5: Yes.

R1: And C6, you said you prefer to use the sheets again.

C6: Yes, because it helps you to remember things. "

Below you can read a quote from the interview with H8. This parent is also a teacher on a primary school and mentions that the worksheets help in having the children think about what they are doing.

" H8: On the other side I notice, also using my own experience as teacher, that you want children to also learn to think and not just learn crafts. This way you can pause them, it is something a lot of children have that they just want to work. 'I just want to make. I will start, miss.' 'Okay, but I first want you to write down what you need.' 'But I know it.' 'That can be, but I want to know.' And this allows that, that's something I really like. To be honest, I also scanned the materials, because it is really nice. It is a nice guide, you can really slow them down and let them work step-by-step "

Conclusions

Using the worksheets helps the children to work structurally, purposefully and forces them to think about what they are doing. They have to literally stop doing something to fill in a sheet before they can continue with the next step.

Changed goal
Most groups kept the same goal during the whole process. There was one group that shifted (unconsciously) towards another goal when they started with the plan of approach. Figure 42 shows the specific goal they set for their prototype and the change to the overall goal of the assignment. The boys filled in the goal worksheet and H1 filled in the Plan of approach worksheet and mentioned the overall goal as goal and wrote that down on the sheet. No one corrected her and from there on they used the overall goal and never looked at their goal worksheet anymore.

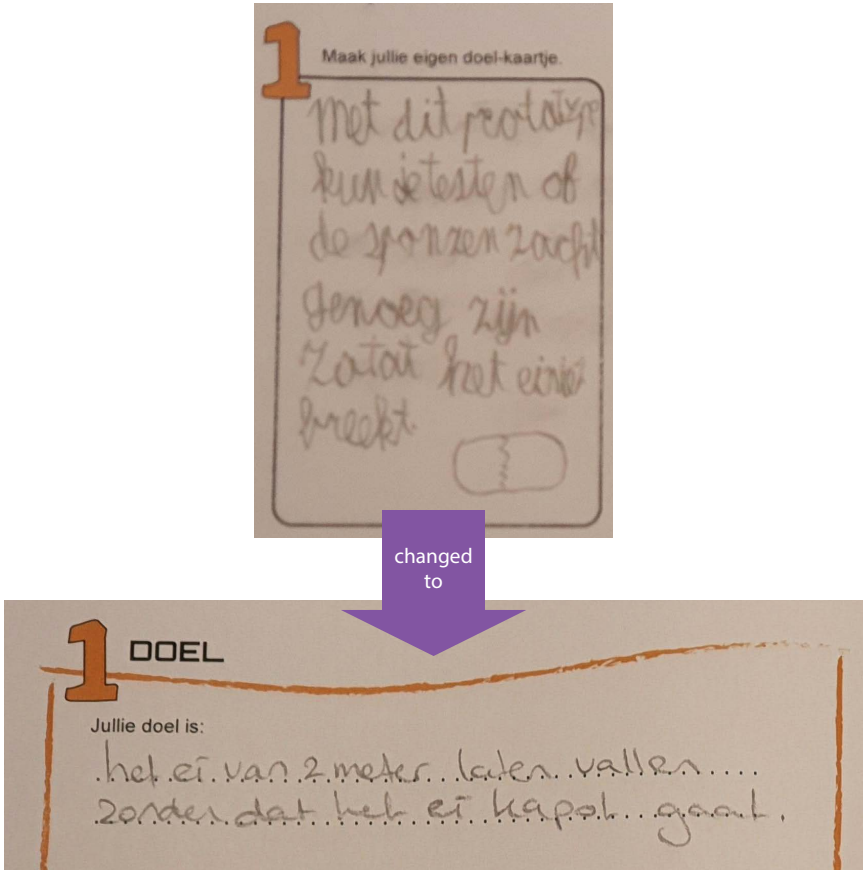


Figure 42. *Change in goal of C1 and C2*

Conclusions

Writing down a goal as group is not a guarantee that the group will keep that goal in mind, but for most groups it was enough to write it down once and keep on working towards that goal.

Outcome test vs goal
The Test worksheets asks the children to reflect on their goal and prototype. C9 was able to see that testing and finding out that your solution did not work, does not mean that your prototype was wrong. You could still test your goal. Below you can read a fragment of the test of C9 and C10 while they are answering the second statement of the Test worksheet: We have to adjust our prototype to make it better fit to our goal.

" H6: We have to adjust our prototype to make it fit better to our goal?

C10: Yes

C9: No, completely disagree.

C10: Completely agree.

H6: Why do you not agree C9, and C10 do agree?

C9: Well, we tested whether it stayed balanced, we did that and therefore it is good.

...

C9: Yes okay, but did you see whether it stayed balanced?

C10: Yes

C9: Yes, meaning our prototype is good, right?

C10: Oh, yes.

C9: We are not talking about adjusting the thing, but about what our goal was. "

Conclusions

Children are able to see the outcome of the test separate from having success or not. When you do not meet your goal it does not mean you made a bad prototype. It means you learned from it and have to find another solution.

Iterating

Table 5 shows all the goals and new goals of the groups. Their own words are translated to English.
Most groups had as goal to test whether their idea would protect the egg and that the egg would not break. Some groups made their goal more specific and named parts of their design with the purpose to make sure that the egg would not break.
C9 and C10 were the only ones that had a goal that did not involve an egg. They looked at the core of their idea and if their construction would flip and land on the wrong side, they would know the egg would have been broken.
6 out of 9 groups managed to protect their egg. When setting a new goal some of these groups used their experience while making, testing and checking their prototype to come up with a new goal. Other groups were struggling more to come up with a new goal, because they completed the assignment and did not know how to continue. In the end all groups did come up with a new goal related to their process experiences.
3 out of 9 groups ended with a broken egg or the knowledge their egg would break. For these groups is was easier to come up with a new goal. They reflected on their process and idea and looked at what they could do differently.
One group did not test their goal or set a new goal because they did not think they had a prototype to test with.

Group	Goal	New goal	What happened?
C1 & C2	With this prototype you can test whether the sponges are soft enough to make sure the egg will not break.	Make sure nothing breaks by making it super firm and placing the heaviest part of the construction below.	The egg broke and in the test they noticed that how it fell on the ground might had to do something with some parts being heavier than others.
C3 & C4	1) With this prototype you can test whether the egg goes slower. 2) Test whether the egg is protected (and doesn't break).	This prototype makes sure you can test testing.	Both eggs broke, but with the second test they could not tell whether it was because of the fall or if it happened while unpacking.
C5 & C6	With this prototype you can test whether something fragile breaks.	With this prototype you can test whether something fragile breaks.	The egg did not break and they mention that they want to see whether it would also not break from greater height.
C7 & C8	That the egg doesn't break.		In their eyes they did not have a prototype and therefore could not do the test.
C9 & C10	With this prototype you can test whether it stays balanced.	With this prototype you can test whether the parachute works.	The prototype landed on the wrong side. The new goal is about another part of their initial idea.
C11 & H7	With this prototype you can test whether it is strong enough.	With this prototype you can test whether it is easy reusable.	The egg did not break. During the test they noticed checking whether they achieved their goal was a hassle.
C12 & C13	With this prototype you can test whether there is enough damping.	With this prototype you can test until what height the egg doesn't break.	The egg did not break and they wanted to know if it also doesn't break from greater height.
C14 & C15	Egg should not break.	Egg should not break.	The egg did not break. For the new goal they want to test a variant of their idea.
C16	With this prototype you can test whether it is strong enough.	With this prototype you can test whether you have the time for it.	The egg did not break. She met her goal but thought the process took her too long.
C17 (& C18)	To test whether it really works.	With this prototype you can test whether people would buy it.	The egg did not break, but the prototype didn't look pretty.

Table 5. *All the goals and new goals per group*

New goal worksheet
A few groups saw the Goal and New goal sheet as the same thing and wondered why they had to do it again.

“ C1: We already did this. ”

Some groups struggled with thinking of a new goal. Below you can find a fragment of the interview with C5 and C6. They struggled with setting a new goal after achieving their first goal, but in the end managed to come up with a new goal.

“ C5: That one we did not understand. We thought that one was difficult because, uhm. We didn’t really understand. Because the goal stayed the same, because. Because you had to test whether something fragile won’t break. So yes, we didn’t really understand.

C6: It looked a bit like the other goal.

C5: Yes.

C6: So we wrote down what we already had on the goal.

C5: Yes, on the other goal.

R1: But in the end, if I understood correctly, you wanted to drop it from a greater height? What will happen then? Right?

C5: Yes. ”

Conclusions

The Iteration tool stimulates children to think about iteration and developing their idea. For all the groups with a new goal, the goal was related to either their process experience, outcome of the test or initial idea. Since the test stopped after setting a new goal, I cannot conclude that the tool stimulates iterations but it does stimulate the process of thinking about iterating.

The moment a group achieves their set goal, it is harder to come up with a new goal. In their eyes they achieved what they wanted, so they do not see the benefit of creating a new goal. It is possible that they are not aware of the possibilities that they have once they tested a goal.

The Goal and New goal worksheet look very similar, so similar that multiple groups saw it as the same and wondered why they had to do it again.

Plan of approach

Using plan of approach

Most groups used the plan of approach during their process. C16 and C17 did not use the plan of approach they made. They both made the prototype by themselves.
One group mentioned that they did not use their plan of approach since it had only two tasks, one per child, and they were able to just remember the task.

Multiple groups actively used their plan of approach and also moved their tasks once they were finished with it. All the groups saw the benefit of a plan of approach if you work with a group. Below you can find a few quotes from the interviews which show what the children thought of the plan of approach and how they used it during the process.

" C3: I think it was useful because you knew when a task was finished and what else you had to do. "

" R1: What did you think of making a plan of approach like this?

C9: Yes, nice and useful. It shows you what you have to do and what you need to do it, how long it takes and you know that everyone is spending the same amount of time on it. "

" C5: I first looked at one task, execute the task. Then placed it at done. Then I looked at the next task, so I didn't read them all at once and executed them in one go. I did try that, but then I already forgot the second task. So I had to look at it again. "

Collaboration

Two groups mentioned that the collaboration was better because they had a plan of approach that they could follow. This way they knew who did what, see a quote from the interview below.

" R1: C13, do you know? Do you think the collaboration was better due to the plan of approach, or worse?

C13: Yes, I think so, it improved because we knew one does this and the other does that. And that improves working. "

Conclusions

The plan of approach is a good contribution to the tool. It allows children to really think about what they are doing and helps them in creating a clear overview of what has to be done and by whom. In some groups it also made the collaboration better, because everyone knew what to do and what their share of the work was.

For children using a plan of approach when working alone seems needless. A plan of approach is also less useful when there is a low amount of tasks that have to be done.

Creating tasks
Not all groups managed to write down specific tasks. Some groups wrote down the materials needed. Below you can find a fragment of the test of C5 and C6. C5 is writing down the time needed for each tasks, but his mother thinks the task should be more than what he had written down. Instead of creating an extra task C5 just writes down that it will take longer.

" C5: For each task write down the time and materials needed to execute it.

H5: You already wrote down the materials, that are your tasks. So how much time do you need, for example to cut the sponges and put them in the box.

C5: Tape for the box, 5 seconds. Since it's laying there.

H5: Yes, that's really short, you can just grab it. I do find it impressive if you can also tape the box closed in 5 seconds.

C5: Oh yes, but this is getting, right?

H5: Yes okay, but I think you also need to take into account that you have to use it.

C5: Let's make it 5 minutes. "

There was one group more focused on the number of tasks than on the content of the tasks and whether the set was complete in order to make their prototype. With guidance from the parents they managed to create a complete set of tasks. Below you can find a fragment from the test of C1 and C2 in which H2 checks whether the tasks list is complete by asking question.

" C1: I think this is enough.

H2: Yes? So if you do foil around the egg and glue the sponges, then your whole prototype is finished with C2's part? Or do you have to do more to make it complete? "

Conclusions

Creating a complete set of (sub) tasks is not something all children already know how to do. Some children need more guidance and practise in thinking of (sub) tasks.

Reflection moments

Checkpoint
For multiple groups the checkpoint interrupted the flow of making. Below you can find a quote from the interview of the helpers of C1 and C2 about the checkpoint being an interruption.

" H2: It was an intense interruption.

H1: I think because it was in such a short time span. "

Even though the checkpoint felt like an interruption for some, other groups saw the value of the checkpoint and liked it. For C9 and C10 the checkpoint helped them in their process, see a quote from their interview below.

" H6: At a certain moment we used the checkpoint. To see how it was going. Is everything still clear? What do we need to do differently? So that went quite naturally. At a certain point you felt that it was a good moment to check how everything was going.

C9 or C10: Really nice. "

Only two children younger than 13 knew the meaning of 'checkpoint' and one of them goes to an international school. Only one child did not know the meaning of 'tussenstop' (checkpoint translated in Dutch).

Conclusions

A checkpoint can be very valuable, but has to be used at a fitting moment. Most groups build their prototype in 20 minutes and having to stop while you just started was experienced as annoying and disturbing.

Checkpoint as not a good title of the worksheet since almost none of the children understand the meaning of the word. 'Tussenstop' is a better title.

Looking back

Figure 43 shows the Looking back worksheets of two groups which are representative for all groups.

C3 and C4 wrote that the step-by-step plan was good, the game was nice and that C3 would do the same again.

C5 and C6 wrote down what elements they would use again to make their prototype and what function it would have. And they would replace the plastic for environment friendly materials.

Conclusions

During the reflection at the end the children do not really go in depth. They either mainly reflect on the prototype they made or just mention some things from the process they would do or do not do again. They do not explain why something is good or bad.

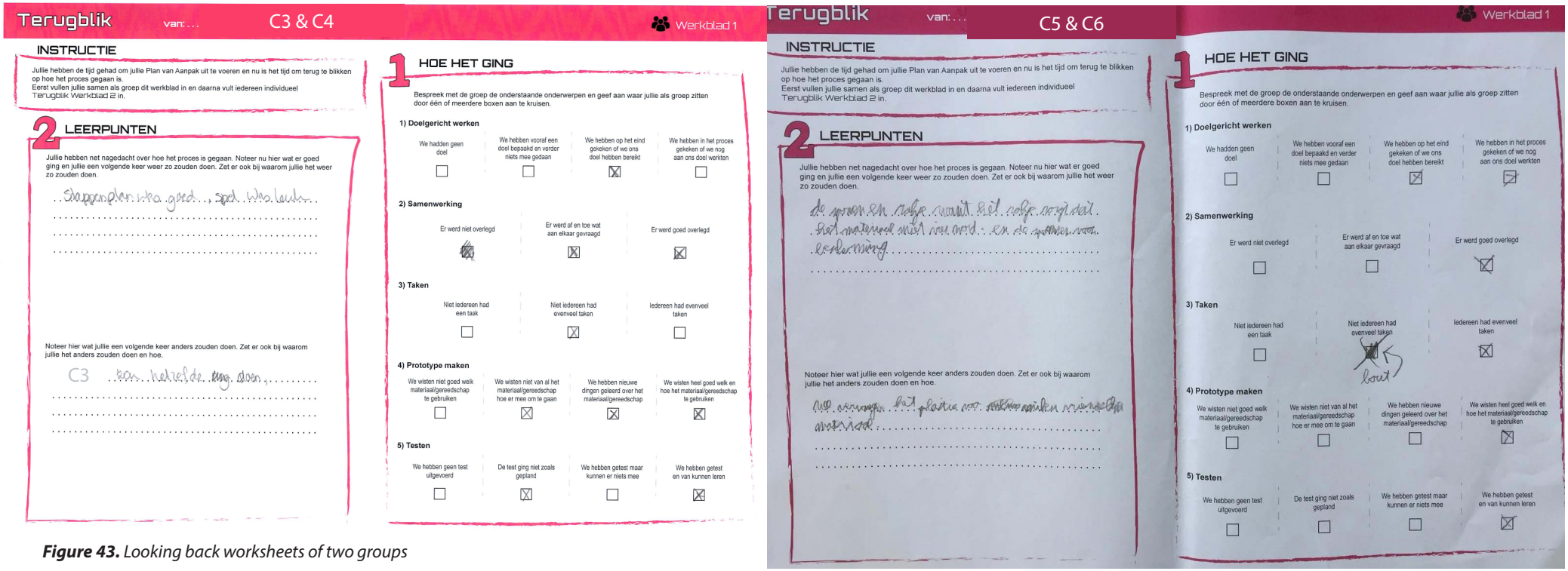


Figure 43. *Looking back worksheets of two groups*

10.5 Info booklet

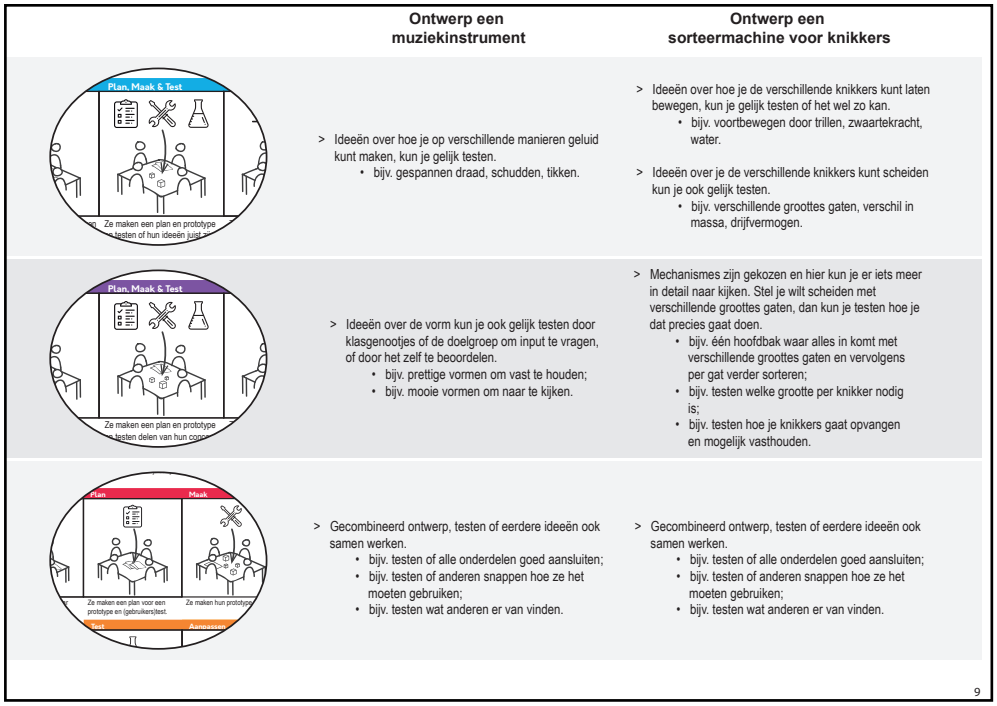
In this section the results and conclusions of the test of the Info booklet are presented.

Understanding the content

Both teachers were able to understand the content of the Info booklet. They mentioned that the figures were clear and informative. Especially page 9 (see Figure 44), the examples of possible prototypes and tests per phase of the design cycle, was inspiring and triggers the teachers.

Using the content

Both teachers mention the booklet would be useful to use while preparing an assignment and facilitating in the process, but for one of the teachers the booklet could be more practically oriented. The booklet is very theoretical and she mentions that when she reads something useful, she would want to know how to use and implement it directly in her classes. She mentioned that figure 3 (see Figure 45) is interesting, but she would want to know what the materials for children look like.



	Ontwerp een muziekinstrument	Ontwerp een sorteermachine voor knikkers
	> Ideeën over hoe je op verschillende manieren geluid kunt maken, kun je gelijk testen. • bijv. gespannen draad, schudden, tikken.	> Ideeën over hoe je de verschillende knikkers kunt laten bewegen, kun je gelijk testen of het wel zo kan. • bijv. voortbewegen door trillen, zwaartekracht, water. > Ideeën over je de verschillende knikkers kunt scheiden kun je ook gelijk testen. • bijv. verschillende groottes gaten, verschil in massa, drijfvermogen.
	> Ideeën over de vorm kun je ook gelijk testen door klasgenootjes of de doelgroep om input te vragen, of door het zelf te beoordelen. • bijv. prettige vormen om vast te houden; • bijv. mooie vormen om naar te kijken.	> Mechanismes zijn gekozen en hier kun je er iets meer in detail naar kijken. Stel je wilt scheiden met verschillende groottes gaten, dan kun je testen hoe je dat precies gaat doen. • bijv. één hoofdbak waar alles in komt met verschillende groottes gaten en vervolgens per gat verder sorteren; • bijv. testen welke grootte per knikker nodig is; • bijv. testen hoe je knikkers gaat opvangen en mogelijk vasthouden.
	> Gecombineerd ontwerp, testen of eerdere ideeën ook samen werken. • bijv. testen of alle onderdelen goed aansluiten; • bijv. testen of anderen snappen hoe ze het moeten gebruiken; • bijv. testen wat anderen er van vinden.	> Gecombineerd ontwerp, testen of eerdere ideeën ook samen werken. • bijv. testen of alle onderdelen goed aansluiten; • bijv. testen of anderen snappen hoe ze het moeten gebruiken; • bijv. testen wat anderen er van vinden.

9

Figure 44. *Page 9 of the Info booklet*

Tips

The booklet has 7 tips for teachers. One of these tips is about useful materials for prototyping. One of the teachers mentioned she would also want to know what tools you would need for those materials.

Conclusions

The Info booklet provides teachers with useful information about the role of prototyping in a design process. The information would be more useful if it is a bit more practically oriented to support the teachers and help them with directly implementing it in class.
The tips section is missing a tip about what tools are recommended to have available when prototyping.

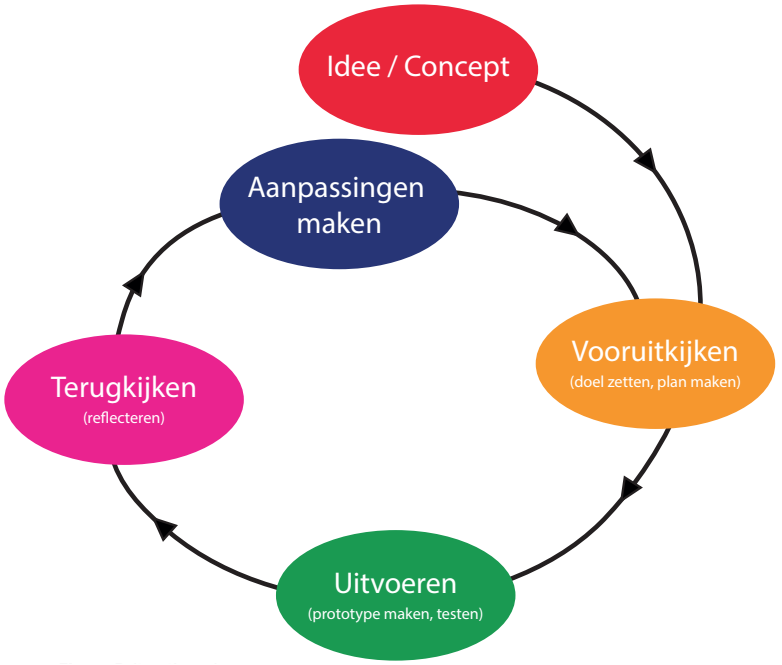


Figure 45. *Figure 3 of the Info booklet*

11. Discussion

This chapter discusses the results and conclusions.

11.1 Skill tool

Using the Skill tool

The Skill tool is only tested by two children therefore the conclusions are not that strict yet. The intervention (see Figure 38 on page 49) helped participant 2 in executing the last step. Since he had already executed one skill card before using the intervention it could also be that it was already easier to do because he had done it before. Another explanation could be that he would know the second material better, but this is not likely since he mentioned the skill deforming iron wire was new and that he struggled a lot with using the pliers.

Form of the skill cards

Both participants mentioned that they prefer the skill cards on paper over it being an instruction video. Both participants do not have dyslexia. For children with dyslexia an instruction video might be preferred over a physical card with text and images since they struggle with processing text.

Selection of skills

Not all the skill cards are tested, but the tests do give the impression that skills in the set are diverse enough for children to be interesting and useful. A teacher or child can make a decision based on available materials at that moment. Or can look at which skills and materials are new to them and seem interesting to learn. An advantage of the skill tool is that it provides multiple processing options for a material.

Skill tool at home vs. Skill tool at school

The participants tested the Skill tool at home, while its intended use is in primary education at schools. One participant managed to execute the skill cards by himself and for him it probably does not matter if it was in his backyard or if it would have been at school. The other participant needed more help from his mother. At school he would have been able to ask his teacher for help and then he would also have classmates that could help him.
The insights from this test can be translated to using the Skill tool at school. The main difference between testing at home and at school would be the size of the test group. There need to be more children to test the skill cards and preferably at school to see what the interaction between children would be when executing the steps.

11.2 Prototype-discussion-game

Playing the game

The group that tried to play the game without the presence of their parents did not understand the game. This could mean that the instructions are not clear enough for children to understand by themselves. In class a teacher would probably first explain the game to the whole classroom before the children would play the game. This will probably help the children in understanding what they need to do.
The group also did not look at all the materials before concluding that they did not understand the game. By first explaining the game to the whole classroom all the children will already have seen all the materials before reading the instructions by themselves.

Even though most groups used the playing field in a different way than the intended way, it probably did help and stimulate in creating prototype-goal pairs. They were filling the empty spaces and multiple groups also wanted to continue until all the spaces were filled. The playing field visually reminded the groups of the need to make a decision and create a pair.

Discussing

There still was not a lot of discussion between the children about the different goal-cards. When the children talked about the goals they looked at the prototypes and asked themselves the question whether it was important to test their goal with that specific prototype. Nadine had changed the wording from a question to a statement. It seems that this helped the children to talk about goals and prototypes instead of talking about the outcomes of a test with a specific goal. For example in a previous version the children would look at the prototype and say 'The proportions are not right of this prototype, so this goal fits.' And in the version in this project the children talked about the importance of knowing whether the proportions are right.

Another addition of Nadine was the word 'omdat...' (because...). In the test of this project the children often read their goal-cards aloud and after the because often followed the argument for their choice. It seems that this addition triggers the children to share their arguments.

As mentioned there was still not a lot of discussion about the different goal-cards. This can have several explanations. One would be that the game still does not trigger or facilitate a discussion enough. Or that it is too hard for children to defend their choice. Another reason could be that the children just agreed and did not need a discussion to come to a prototype-goal pair.
In the test the game is mainly played with 2 players, there was only one group that played the game with 3 players (2 children and their mother). With just two players there are less options which probably makes it easier to choose from than when you would play it with 4 players. When playing with more children there are more opinions to take in to account and this will probably lead to a bigger need to have discussion.
Another possibility is that the lack of discussion could be due to the age difference and therefore cognitive level of the children within a group. When playing the game with peers it is probably easier to discuss something because your way of thinking is more in line. The boy of 14 years old was having a discussion with his mother about their choices, this could mean that discussing better fits older children, but it could also mean that a 14 year old thinks more in the same way as a mother which allows them to have a discussion.

Learning from playing the game

Having played the game helped groups in setting the goal for their prototype. You could see this because they used the goal-cards as inspiration and most groups used the same wording as used on the goal-cards.
Even tough there was not a lot of discussion about the goal-cards, the children probably still learned about different goals for prototypes. All the groups were able to come up with a fitting goal for their prototype.

The first time playing the game will probably teach children the most. Playing the game again can still be educational since a next time you will have a different combination of goal-cards to choose from and have to think of new arguments.

The goal of the game is to make children aware of different goals prototypes can have. In order for this to happen there does not have to be a big discussion about the different goals. When the children are able to come up with arguments for their chosen goal-cards and find a way to create pairs they agree on, the game serves its purpose.

Prototype-discussion-game at home vs. Prototype-discussion-game at school

The expectation is that there will be more discussion in a group in a classroom than there was at home, because the groups can be bigger and have roughly the same cognitive level.
At home the parents facilitated the game by asking questions. At school a group will not have a teacher present the whole time, so they will need to facilitate the game themselves. It could mean that the groups will go off track more than they did while playing at home.

11.3 Iteration tool

Using the worksheets

There was one group who executed the assignment without the presence of their parents. This group was not able to use the sheets in the intended way. All the other groups did use all the worksheets in the intended order, so it could mean that the worksheet are not clear enough for children to use by themselves and that there needs to be some guidance for children to be able to use the worksheet well. It is hard to tell from just one group whether the sheets should be changed, to become self-explanatory. It could be that their attitude influenced their capability to execute the assignment in the intended way. One of them was relying on the other one to tell him what to do, so you could say that this child was not fully involved in trying to understand what to do and was more waiting for instructions. This group also struggled with keeping an overview due to all the separate sheets, this can also influence their capacity to understand what to do. It is hard to say in what extend the worksheets contributed to the confusion and being able to use the sheets in the intended way, and what was caused due to misunderstanding of the overall assignment.
Since the one group without guidance from adults struggled so much with keeping an overview and using all the worksheets, it seems beneficial to first introduce the Short version of the Iteration tool. This way the children get familiar with the steps they need to take and have it all on one sheet, which allows them to have an overview and see in one glance what steps need to be taken. The group that lost the overview said that the Iteration worksheet would have been clear and would have helped them to do what they were supposed to do.

The test shows that filling in all the sheets is perceived as a lot of work by some groups and was not really in proportion with the time needed to execute the assignment. It could be that the work is perceived as less when the group is bigger. It is also possible that it seems out of proportion because they are not used to working very efficiently and normally take a long time building a prototype, while their plan of approach made building go faster.

Working purposefully

Mainly the Goal worksheet and Plan of approach help the children in working purposefully. With the Goal sheet they set a clear goal for themselves and with the Plan of approach they think about all the things they need to do. When executing their plan they have a clear list with steps they need to take, which allows them to easily stay on track for their goal.

One group changed their goal during the process unconsciously. It could be that a Goal worksheet is not enough for a group and that they need to reminded of their goal more often. It could also be that the assignment made it very confusing because it already had a clear goal in it.

Only one group changed their goal in the process, so for most groups the sheet was enough to set a goal and work towards that specific goal throughout whole process.

Iterating

The New goal worksheet is quite confusing for children. The Goal and New goal worksheet were seen as the same. With the New goal you indeed set a goal again, but with more knowledge and as a new step in the process. In order to make it feel as a new step, it is probably better to not have it look exactly the same as what they already filled in at the start of their process.

Plan of approach

The Plan of approach is a big help when you have to work together. By creating a plan all group members know what they have to do and how the can contribute to the end result.
When working alone a plan of approach can still be useful, but when working alone you are not dependent on others and can easily change something without having to discuss with others. By creating a plan of approach as a group you also make an shared agreement on what things need to be done and what things do not need to be done.

Reflection moments

In order for the Checkpoint to be valuable it is important to use the Checkpoint at a logical moment. Logical moments would be at the start of a new class, after working for an hour or when a group is stuck. When a group is a bit stuck, the checkpoint helps them to get back on track.

During the reflection at the end the children did not really go in depth. It could be that the assignment did not allow them to go in depth because it was too short, but it could also be that it is a skill that is new to them and has to be taught. It could be that they need more help and guidance to start the needed thought process and that it was not beneficial that most group first did step 2 'learning points' before step 1 'how it went'.
In order to help children learning how to think while reflecting, it is beneficial to start with the Classroom reflection. This way the teacher can guide the children more, help them to go in depth in their reflection and teach them how to reflect.

Iteration tool at home vs. Iteration tool at school

The tool is now tested at home. Using the Iteration tool at schools will be different than using it at home. At home there was a parent present all the time and making sure the children understood everything and providing them with the needed worksheets. At school the groups would have to work more independently. At schools it will be important that at the beginning the teachers explain well what the different steps are and how to use the worksheets.
Since there is not a constant check from an adult at school, a group will probably get off track more than what happened at home. In what extend this will happen and what the role of the worksheets will be, is something that has to be researched by testing the tool at school.

11.4 Info booklet

One teacher now has group 1/2 and has had group 5 in the past and the other teacher has group 6. During the test period schools were closed due to COVID-19, so the teachers did not have the opportunity to use the content and find out whether the content is useful when preparing class. Therefore, their opinion is partly hypothetical and further research is needed.

11.5 Requirements and wishes

Design goal 1

Chapter 3 shows the design goal 1 and which requirements should be met to reach the design goal. In Figure 10 on page 24 you can find which requirement belongs to which tool. In this section each requirement and wish is evaluated.

Stand-alone tool

R1.1 The tool should be self-explanatory for teachers.
R1.2 The tool should be usable for almost all children in mainstream education.

The test shows that the Iteration tool is self-explanatory for adults. The adults were able to guide the children through the process. There was one parent that is also a primary school teacher and she was also able to facilitate the session and explain the worksheets. It seems like the tool will be self-explanatory for teachers, but whether this is really the case should be further researched. To test this it is important to provide the teachers only with the information they would get when it would not be a test.
All children that could ask for help were able to use all the worksheet of the Iteration tool. Both children testing the Skill tool managed to use the skill cards. They are in different schools, so this could imply that the tools are usable for almost all children in mainstream education. On the other side, participating in this test was voluntary, so all the children were enthusiastic and eager to participate. Testing the Iteration tool and Skill tool with a full class should indicate whether the tools are usable for almost all children.

Core of prototyping

R1.3 The tool should stimulate iterations.
R1.4 The tool should force children to set a goal for their prototype.

The test of the Iteration tool did not test whether the children iterate with the tool. The results did show that all the groups were able to think of new goals that are related to

what they learned during their process. If they would have continued with their new goal they would be iterating.
All the groups had a goal for their prototype and worked together towards the same goal.

Moment of prototyping
R1.5 The tool should be applicable in multiple phases.
R1.6 The tool should be applicable multiple times during a design process.

These requirements could not be tested in this project, so further research is needed to find out whether the Iteration tool meets R1.5 and R1.6. The test did show that filling in all the sheets is a lot of work and was not really in proportion with the time needed to execute the assignment. So it could be that the current form is not the best form for applying it multiple times in a design process. It could also be that the work is perceived as less when the group is bigger, meaning the current form is fine for applying it multiple times.

Approach
R1.7 The tool should force children to create a clear plan with what needs to be done, how and by whom.

All groups had a plan of approach and all groups of two children with more than two tasks used their plan while building their prototype.

Reflection
R1.8 The tool should provide reflection moments on the progress and process of the children.

The Checkpoint and Looking back worksheet of the Iteration tool made the children reflect on what they were doing and if needed they adjusted their approach.

Skills and knowledge
R1.9 The tool should provide the children with knowledge of different goals to prototype for.
R1.10 The tool should provide the children with knowledge of different ways to prototype.
R1.11 The tool should stimulate children to learn new skills which can be applied in prototyping.

By playing the Prototype-discussion-game the children learned about different goals to prototype for.
There are multiple skill cards on how to use cardboard, which teaches children that cardboard can be used in multiple ways when prototyping. For both children that tested the Skill tool their chosen skills were new to them.

Wishes
W1.1 The tool should allow teachers to adjust the format to their preference.
W1.2 The tool should be self-explanatory for children.
W1.3 The tool should provide enough tasks for prototyping to enable all children to contribute to the process.
W1.4 The tool should make the children reflect in depth on their process.

In the Skill tool teachers can choose whether they want all children to do the same skill card or whether the children can choose from a pre selection or whether they can choose from the complete set. In the Iteration tool the teacher can choose between the Short and Extended version and in the Extended version teachers can choose which form of reflecting fits best.
One of the children testing the Skill tool executed the steps without any help from an adult, so for him the tool was self-explanatory. The other child needed some help from his mother. For him it was clear what he needed to do, but it was not always clear how to do it. There was one group that tested the Iteration tool without help from their parents and for them the steps to take were not completely clear.
In the test all children had tasks to execute, but the groups were smaller (2 children) than they would be in school (3-4 children).
Some worksheets of the Iteration tool let children reflect on their progress and process, but the learning points are quite superficial and mainly on their progress. It seems like the teacher will need to play a bigger role in helping the children in their reflection.

Design goal 1
The first design goal is: Make children (9-12 years) use prototyping to iterate in their design process by supporting them in the why and how they can prototype. Due to the test circumstances I can not conclude that the tools make children use prototyping to iterate. I can conclude that the Iteration tool helps children to purposefully prototype and helps them to think of iterations. The Skill tool helps children to learn how they can use materials to prototype with and the Prototype-discussion-game makes children aware of different goals prototypes can have.

Design goal 2

Chapter 3 shows design goal 2 and which requirements should be met to reach the design goal. In Figure 10 on page 24 you can find which requirement belongs to which tool. In this section each requirement is evaluated.

Requirements

R2.1 The tool should be understandable for almost all teachers in mainstream education.

R2.2 The tool should provide the teachers with knowledge on the design process related to prototyping.

R2.3 The tool should provide the teachers with dos and don'ts in facilitating a design process related to prototyping.

The Info booklet is only tested by two teachers, so more teachers should test it before I can conclude that it is understandable for almost all teachers in mainstream education. The booklet provides the teachers with knowledge on the design process related to prototyping and provides them with dos and don'ts.

Design goal 2

The second design goal is: Support teachers in coaching the children through the process related to prototyping. Unfortunately, due to circumstances teachers could not apply their gained knowledge in class because the schools were closed. The two teachers that tested the booklet think will help them in coaching the children, but could not use it and therefore not tell it helped them.

12. Final design

This chapter describes the final design. It presents all the separate elements of the tools and explains how the different tools can be implemented.

12.1 Overview of elements

Figure 46 shows the flowchart presenting in what order and combination the tools can be used. The only change in the structure, compared to the version before the test, is that there is not one manual for the Skill tool, Prototype-discussion-game and Iteration tool. Each tool will get its own explanation sheet in the same lay-out as the Your Turn tools. Each explanation sheet will refer to the other tools and the Info booklet will also refer to all the other tools. By adjusting the tools to fit the Your Turn tools, the tools can be distributed via the already known channels.
The Info booklet, Skill tool, Prototype-discussion-game and Iteration tool can be used in sequence, but also separately. For each tool a teacher can decide to use it or not and independently from their choice they can still use the next tool. When a teacher chooses to use the Iteration tool, (s)he has to decide whether (s)he wants to use the Short or Extended version.
Figure 46 also gives a summary of the content of each tool and of which elements it consists. In the Extended version there are multiple options to use for reflecting, these are presented in italic. Teachers can decide which fits best with the class and design assignment.

All the tools can be used together, but also separately. The tools are designed like this on purpose. It is up to the teacher to decide which tools and elements fit best in their programme. Teachers already have a lot of things they need to implement in their programmes. Interviewees and Science Hub TU Delft both mentioned teachers like to have options in order to create a lesson that fits with their goals and classes. The tools have a supportive role, they are meant to help the teachers in educating the children. A teacher knows best at what stage the children are in their development. So by providing multiple options it allows teachers to shape it in a form that best fits the needs of the children and themselves.

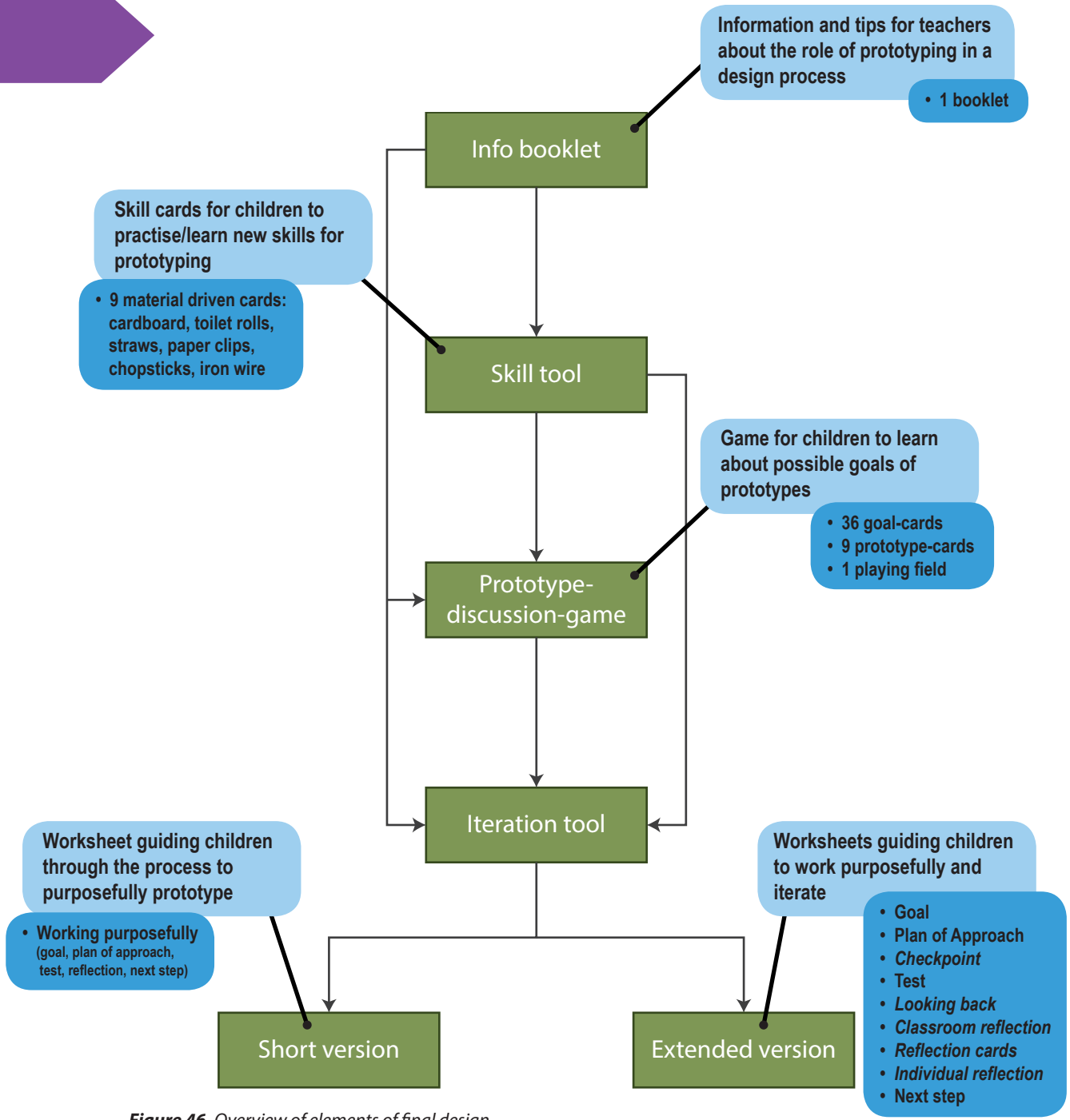


Figure 46. *Overview of elements of final design*

Figure 47 shows in what moments of the design cycle you can implement the tools. There are three moments in which you can implement the Prototype-discussion-game and the Iteration tool. When you use the Extended version of the Iteration tool you can implement it in moment 1, 2 or 3.
When you use the Short version of the Iteration tool you can implement it in moment 3 and moments 1 and 2 would not be part of the process.

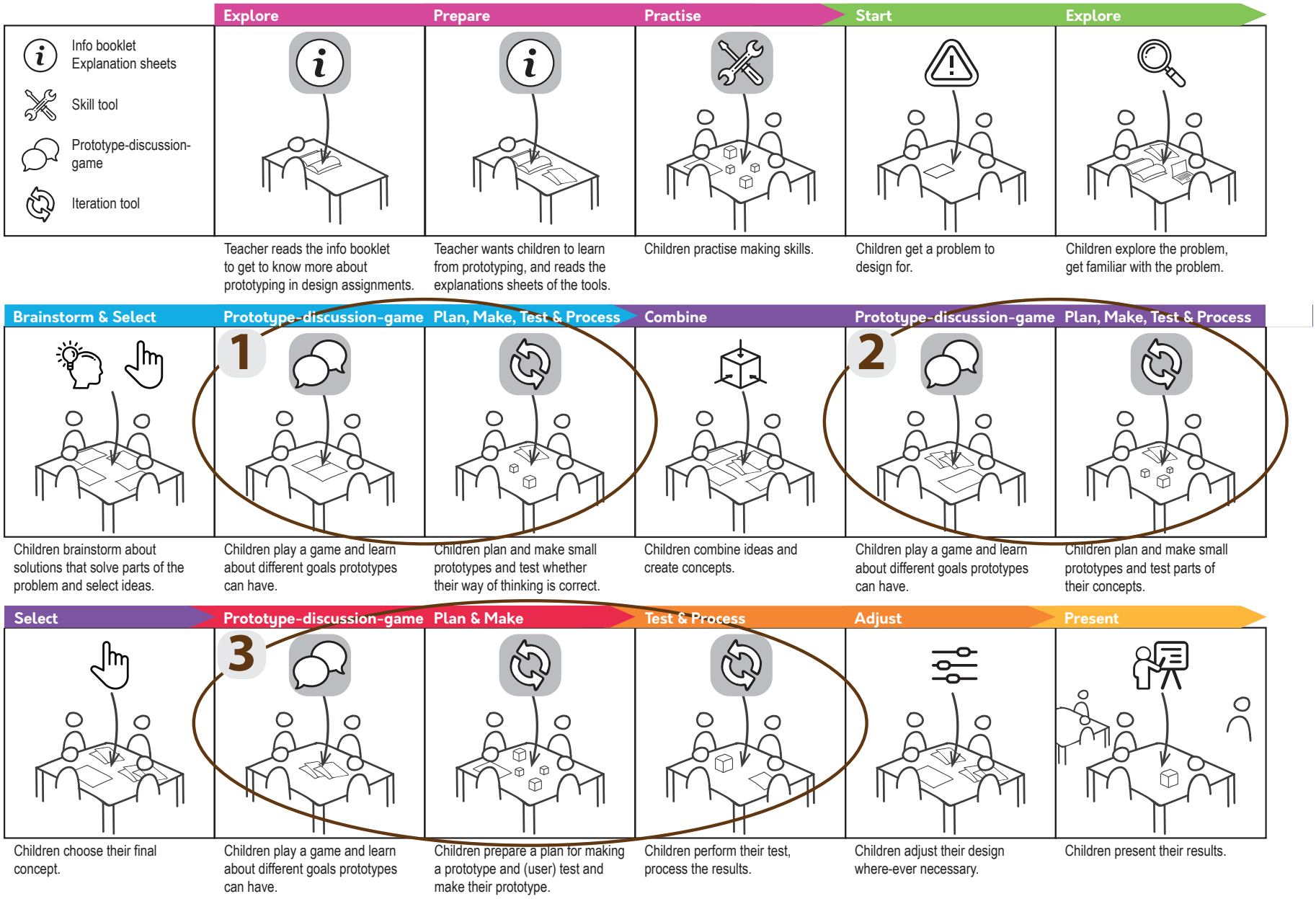


Figure 47. *Using the tools in a design process*

12.2 Info booklet

Figure 48, Figure 49 and Figure 50 show three pages of the final design of the Info booklet. The complete booklet can be found in Appendix 8.

The booklet provides information about the role of prototyping in a design process. The booklet also provides examples and information about tools which can be used in class when prototyping. The booklet shows what the materials for children of the tools look like and where they can find the tools online. This makes it easier for teachers to directly apply the information in their own lessons.

Prototypes maken

Als je naar de ontwerpcyclus kijkt, lijkt het er op alsof je in een ontwerpproces maar één keer een prototype maakt. Een beroepsontwerper doet dit echter vaker. Door het maken van prototypes kun je snel ergens achter komen en die informatie gebruiken om de oplossing verder te ontwikkelen. Het is dus ook waardevol voor kinderen om vaker een prototype te maken in het ontwerpproces.

Om het maken van prototypes gemakkelijker te maken voor kinderen zijn er drie hulpmiddelen ontwikkeld: vaardigheden tool, prototype-discussie-pel en iteratie tool.

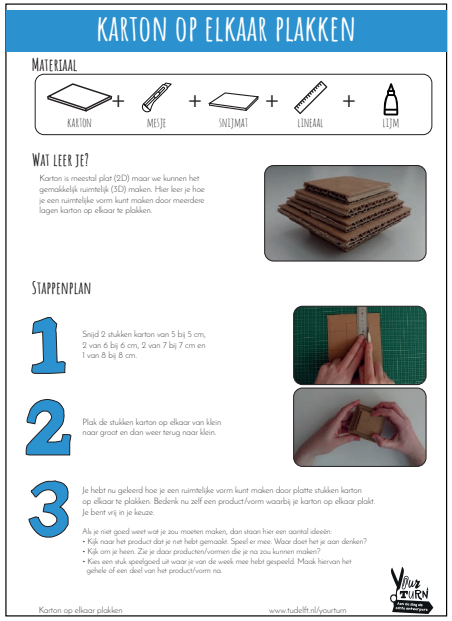
Vaardigheden tool

Om prototypes te kunnen maken moeten kinderen bepaalde vaardigheden bezitten. Met de vaardigheden tool kunnen kinderen nieuwe vaardigheden aanleren en worden ze gestimuleerd om na te denken over hoe ze die vaardigheden kunnen gebruiken bij het maken van prototypes. In Figuur 4 zie je één van de vaardigheden die in de set zit. Via www.tudelft.nl/yourturn kun je de tool downloaden.

Prototypype-discussie-spel

Een prototype maak je met een bepaald doel. Met het prototype-discussie-spel leren kinderen over verschillende soorten doelen die prototypes kunnen hebben. De kinderen moeten als groep bepalen welk doel het beste past bij een prototype. In Figuur 3 zie je een voorbeeld van een doel-kaart (blauw) en een prototype-kaart (geel). Via www.tudelft.nl/yourturn kun je het spel downloaden.

Figuur 3. *Doel-kaart en prototype-kaart*



Figuur 4. *Vaardigheid uit de vaardigheden tool*

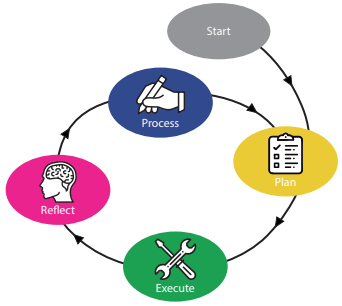
Figure 48. *Final design of page 7 of the Info booklet*

Iteratie tool

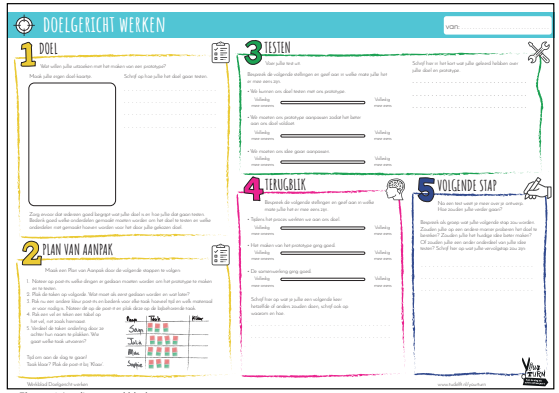
Een prototype maak je om ergens achter te komen. Het is dus belangrijk dat je een duidelijk doel voor ogen hebt en dat je weet hoe je achter de informatie kunt komen die je zoekt. De iteratie tool helpt kinderen focussen op een doel en daar een duidelijk plan van aanpak voor te maken. Het gezette doel en plan van aanpak zorgen er voor dat kinderen doelgericht te werk gaan. Daarnaast laat de iteratie tool kinderen reflecteren op wat ze doen om zo de volgende keer het maken van een prototype weer iets gemakkelijker te maken. Als laatst laat de tool de kinderen nadenken over wat hun volgende stap zal worden.
In het kort gezegd laat de iteratie tool kinderen eerst vooruitkijken, dan uitvoeren, dan terugkijken op wat ze gedaan hebben en als laatste alles wat ze ontdekt en geleerd hebben verwerken, zie Figuur 5.
In Figuur 6 zie je een leerlingenwerkblad van de iteratie tool. Via www.tudelft.nl/yourturn kun je de tool downloaden.

Inzetten tools

Zowel de vaardigheden tool, prototype-discussie spel en de iteratie tool kunnen op meerdere momenten worden ingezet en los van elkaar gebruikt worden. Wanneer de kinderen nog weinig ervaring hebben met prototypes maken en daardoor mogelijk over weinig vaardigheden bezitten die ze kunnen helpen bij het maken van een prototype, is het aan te raden om eerst de vaardigheden tool te gebruiken voor je de iteratie tool introduceert. Het is ook aan te raden om de kinderen eerst het spel te laten spelen voor je ze aan de slag zet met de iteratie tool.



Figuur 5. *Iteratie cyclus*



Figuur 6. *Leerlingenwerkblad*

Figure 49. *Final design of page 8 of the Info booklet*

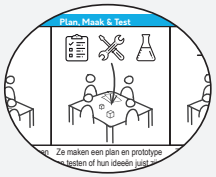
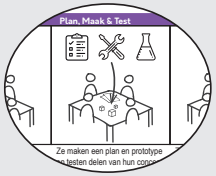
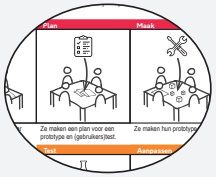
	Ontwerp een muziekinstrument	Ontwerp een sorteermachine voor knikkers
	> Ideeën over hoe je op verschillende manieren geluid kunt maken, kun je gelijk testen. • bijv. gespannen draad, schudden, tikken.	> Ideeën over hoe je de verschillende knikkers kunt laten bewegen, kun je gelijk testen of het wel zo kan. • bijv. voortbewegen door trillen, zwaartekracht, water. > Ideeën over hoe je de verschillende knikkers kunt scheiden kun je ook gelijk testen. • bijv. verschillende groottes gaten, verschil in massa, drijfvermogen.
	> Ideeën over de vorm kun je ook gelijk testen door klasgenootjes of de doelgroep om input te vragen, of door het zelf te beoordelen. • bijv. prettige vormen om vast te houden; • bijv. mooie vormen om naar te kijken.	> Verder in detail kijken naar een gekozen mechanisme. Stel je wilt scheiden met verschillende groottes gaten, dan kun je testen hoe je dat precies gaat doen. • bijv. één hoofdbak met verschillende groottes gaten waar alles in komt en dan per gat verder sorteren; • bijv. testen welke grootte per knikker nodig is; • bijv. testen hoe je knikkers gaat opvangen en mogelijk vasthouden.
	> Gecombineerd ontwerp, testen of eerdere ideeën ook samen werken. • bijv. testen of alle onderdelen goed aansluiten; • bijv. testen of anderen snappen hoe ze het moeten gebruiken; • bijv. testen wat anderen er van vinden.	> Gecombineerd ontwerp, testen of eerdere ideeën ook samen werken. • bijv. testen of alle onderdelen goed aansluiten; • bijv. testen of anderen snappen hoe ze het moeten gebruiken; • bijv. testen wat anderen er van vinden.

Figure 50. *Final design of page 10 of the Info booklet*

12.3 Skill tool

Based on the test results there are a few changes made to the Skill tool.

Overall adjustments

The scale of the images on one skill card is the same. This allows the children to see how the elements relate to each other.

In order to make the actions per step more clear, hands show the actions on the images. In the final design the skill 'deforming iron wire' is explained in more steps than the test version, because the test showed that the steps were not super clear. In Appendix 10 you can find all the final skill cards.

The materials needed to execute each skill card are listed at the top of the card. On some cards the list was not complete, so all the material lists are checked and now complete.

Below the materials list there is an image of the end product of the skill. Seeing the end result next to reading about it allows them to create a better picture of what the skill is about and what they would learn from executing the skill card. They can use this information in their choice for which skill they want to learn.

In the test it was clear that the openness of the last step of the skill cards does not work for all children. Therefore the adjusted last step gives more guidance in what kind of thing the children can make. During the second part of the test, it already showed that this form of guidance is helpful when trying to come up with something to make (see page 49).

The last adjustment is to make the cards more in line with the existing tools of Your Turn. The titles are always in Amatic SC and the main text in Josefin Sans. Josefin Sans is a good font to use since it uses the way we write the a, g, f and is sans serif which is easier for children to read *(Melgers, 2016)*. On the bottom Your Turn sheets always have the Your Turn logo, website and title of the worksheet.

Figure 51 shows the recurring elements of the final design of the Skill tool. When a skill card consists of more than three steps, the steps from 4 onwards are on the other side of the paper.

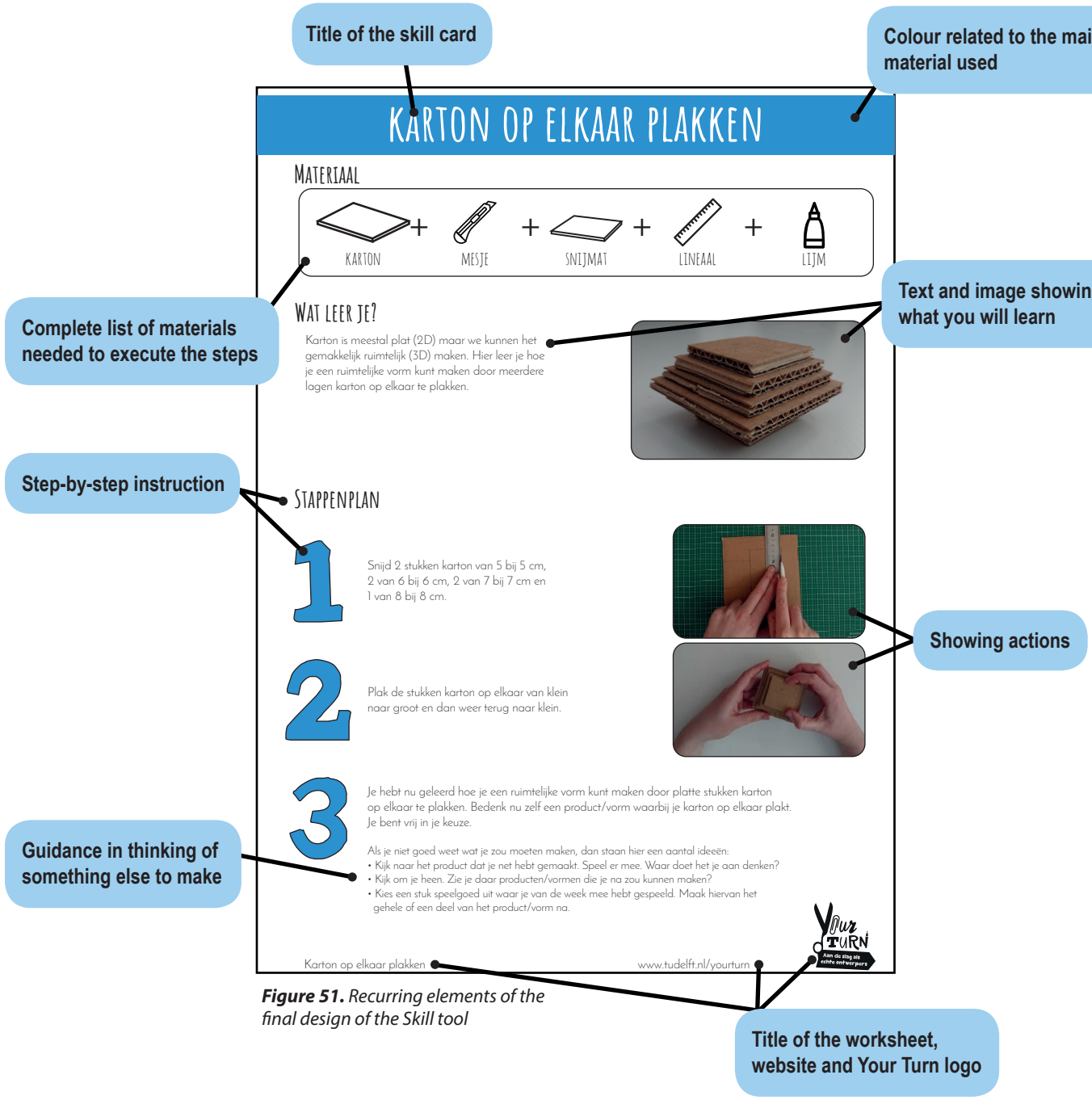


Figure 51. *Recurring elements of the final design of the Skill tool*

Skill set

There was one type of material, that schools often use and can be useful when prototyping, missing in the Skill tool, namely toilet rolls. In order to provide a set of skills that covers the materials schools have available, the skill 'making a tower of toilet rolls' is added to the set (see Appendix 10). Table 6 shows an overview of all the skills in the final design of the Skill tool. It also shows which materials are needed to execute each skill and it shows what colour the banner and numbers have. The colour is related to the main materials used in the skill. All the blue cards have flat cardboard as main material and differ in the gradient. The darker the colour, the more difficult the skill.

Making skill	Materials needed	Colour code
Connecting cardboard using glue	cardboard, knife, cutting board, ruler, glue	Blue
Connecting cardboard using cotter pins	cardboard, knife, cutting board, ruler, scissors, cotter pin	Blue
Folding cardboard	cardboard, knife, cutting board, ruler, pencil	Blue
Connecting cardboard using tape	cardboard, knife, cutting board, ruler, tape	Blue
Sliding cardboard into cardboard	cardboard, knife, cutting board, ruler	Blue
Making a tower of toilet rolls	toilet rolls, pencil, scissors, ruler, glue, cardboard	Green
Deforming iron wire	iron wire, pliers, ruler	Orange
Creating an axle using chopsticks and straws	chopstick, straw, scissors, glue, wheels	Red
Creating a hinge using paper clips and straws	paper clips, straws	Purple

Table 6. *Makings skills of the final design of the Skill tool*

12.4 Prototype-discussion-game

Appendix 11 shows the complete final design of the Prototype-discussion-game. Figure 52, Figure 53 and Figure 54 show the final design of the instruction sheet, cards and playing field. One of the changes compared to the version before the test is the change in font. The font in the final design is Josefin Sans and Amatic SC, just like the other tools of Your Turn. The final design of the instruction sheet and playing field also have the Your Turn logo, website and title of the tool on the bottom. The instruction sheet got its own colour green. To connect the instruction sheet with the playing field, the prototype-goal pair areas have the same colour as the banner of the instruction sheet. The colours of the coloured goal areas on the playing field are slightly adjusted to match the colour green of the prototype-goal pair areas.

Another change made in the final design is to the amount of goal-cards. The game had 27 goal-cards, but this is not enough when you want to play the full game with 4 players. Therefore the final design of the game consists of 36 goal-cards. There already were 12 type of goal-cards, so in the final design each card occurs three times.
With 36 goal-cards and 9 prototype-cards a group with four players can play the full game without running out of goal-cards.

Lastly a small change is made in the explanation of the game. The instruction sheet now explains how to place the playing field and informs the children that the different coloured areas with a goal icon on them are meant for placing their chosen goal-cards on.

Figure 53. *Final design of the cards of the game*

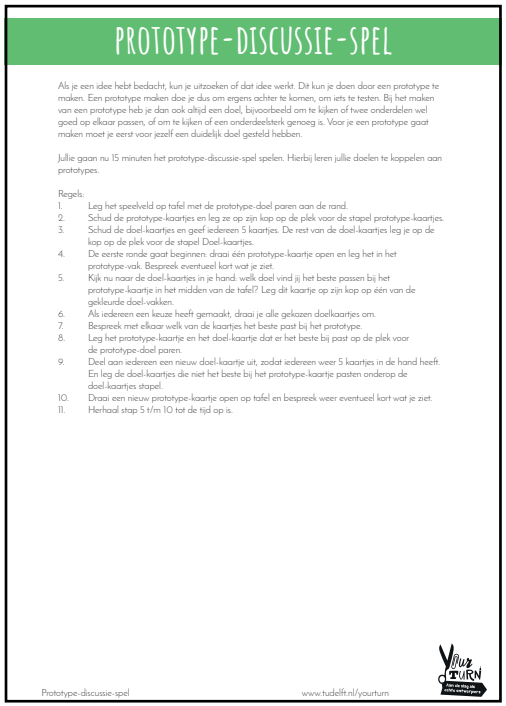


Figure 52. *Final design of the instruction sheet*

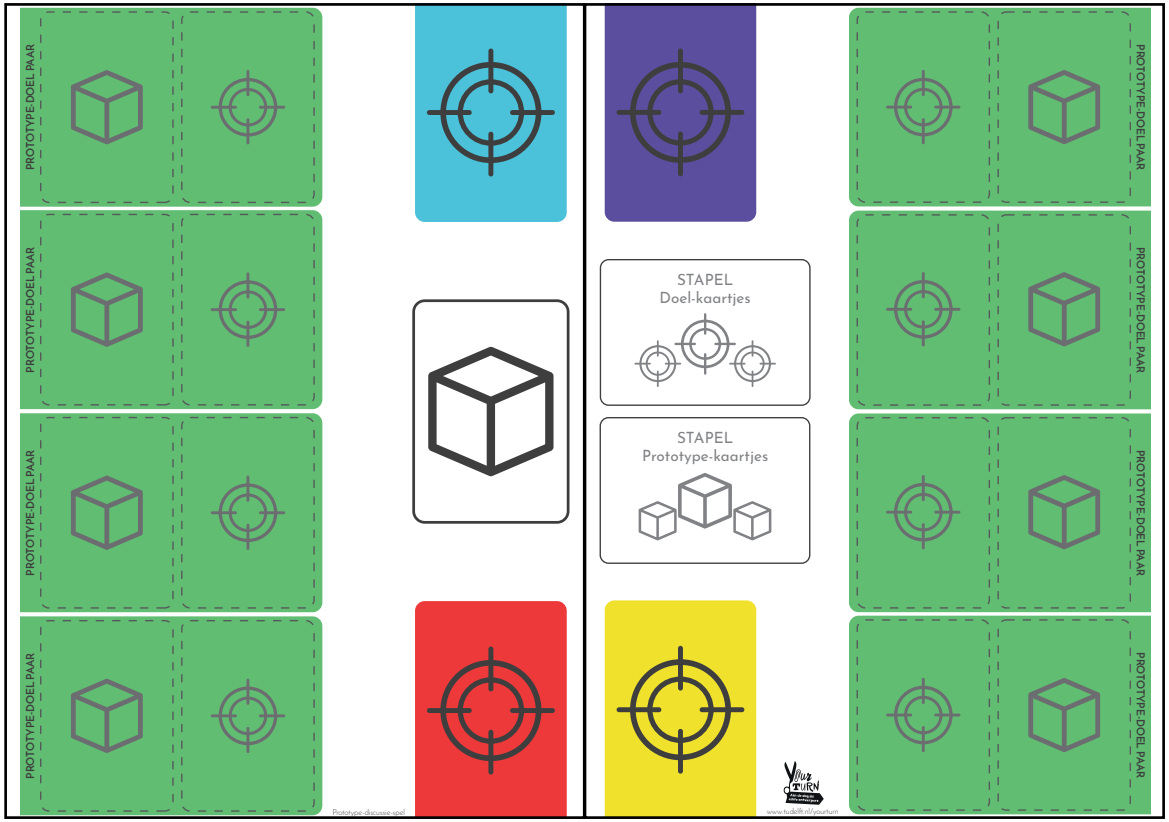


Figure 54. *Final design of the playing field of the game*

12.5 Iteration tool

This section describes the final design of the Iteration tool. Based on the test results there are some changes made to the Iteration tool.

Iteration model

Figure 55 shows the final version of the iteration model. The colours are adjusted in order to distinguish the iteration model from the design cycle. When a teachers wants to print the worksheet in black and white, the different stages should still differ in gradient. With the chosen colours the gradient in black and white is noticeable (see Figure 56).
Another change is that all the stages now, next a colour, also have an icon. This gives an extra visual coherence between the worksheets and stages. The icons are chosen with the input of a 12 year old.
Lastly, the last stage before you enter the new cycle used to be called Adjust. This is now called Process. You do not always have to adjust your prototype or idea after you tested it, but you do always have to process your results in some way. So by changing the name the stage covers a broader range of possibilities and in this way children can never skip this stage.

Short version vs Extended version

Before the test the difference between the Short and Extended version was very small. The main difference was that the Extended version had a checkpoint, a few more questions for the reflection and consisted of separate worksheets. In order to make the distinction and purpose per version more clear, the Short version is now aimed at helping the children to purposefully prototype and the Extended version is aimed at helping children to purposefully iterate by making prototypes. The Short version can be used in smaller design assignments and the Extended version in bigger design assignments, where there is time to iterate.
The Short version will end with a hypothetical question for the children: What if you would continue? What would be the next step? When a teacher thinks the children have very interesting ideas and has extra time available, (s)he can always decide to let the children iterate but the main goal is to make children familiar with the steps they need to take in order to iterate.
The worksheet of the Short version, Working purposefully is on A3 and all the worksheets of the Extended version are on A4. This allows teachers and children to easily fit the worksheets of the Extended version together in a folder.
Appendix 12 and Appendix 13 show the final design of the Short version and Extended version full-scale.

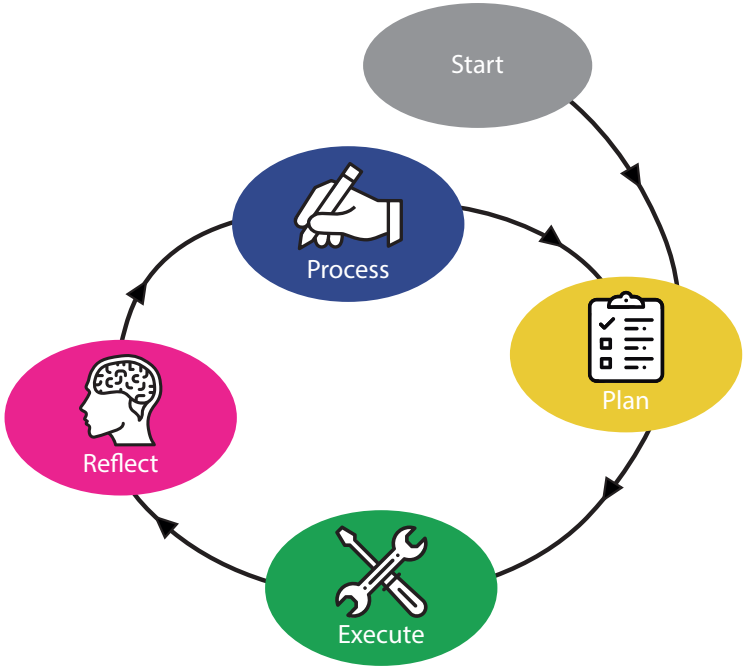


Figure 55. *Iteration model in colour*

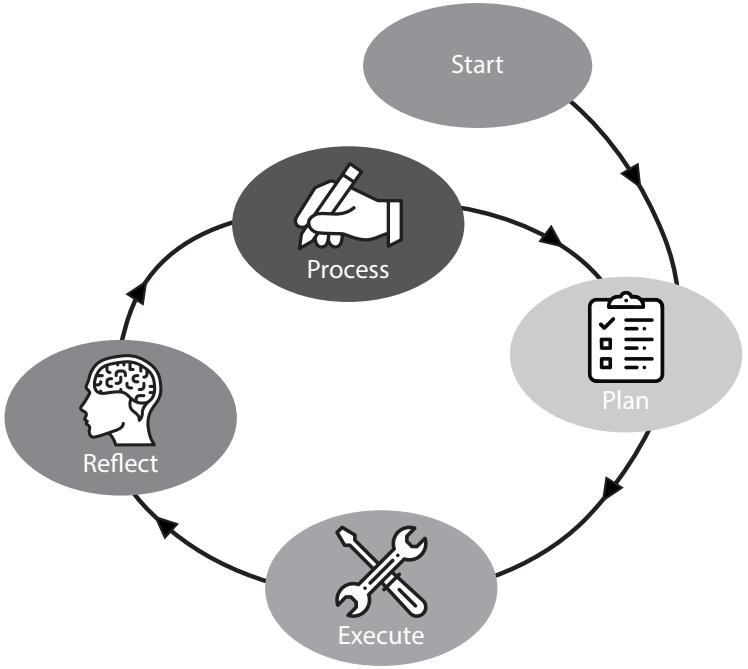


Figure 56. *Iteration model in black and white*

Choices in the Extended version

Figure 57 gives an overview of all the elements of the final design the Iteration tool. It shows in which stages which elements can be used and in which formation they can be used.
In the Extended version teachers can choose which elements they want to use in the Execute and Reflect stage.

Checkpoint
This worksheet asks questions to trigger a discussion about the process. On the worksheet the children need to draw conclusions and make new agreements if needed. Teachers can use this worksheet if they notice a group is stuck. The worksheet lets a group reflect on what they are doing and why. When the executing stage is spread over two moments it is also useful to start the second moment with this worksheet. When you start with this worksheet, the children all get to refresh their memory and start with a shared understanding again.

Classroom reflection
In this method the children get a statement and four answer options. The classroom is divided in four areas and the children go to the area that best fits their experience. Once everyone has moved to an area the statement, answers and experiences are discussed. The children need to physically move and be actively involved. Teachers can help and stir the thinking process of the children by asking questions.
It is recommended to use this method by first time use of the Extended version. Within this method the teacher gets to guide the children through the thinking process and help them in learning how to reflect. In this method children can also learn from each other through their experiences.

Looking back Worksheet 1 and Worksheet 2
Worksheet 1 has several statements and for each statement the group has to indicate whether it applied to them or not. The statements are meant to start the thinking process. On Worksheet 2 the group has to write down concrete learning experiences.
It is recommended to use this method when the children already know how to reflect. This method uses similar statements as in the Classroom reflection and Reflection cards, but takes less time than the Classroom reflection.

Reflection cards
This method consists of several statement cards and the groups have to indicate whether the statement applies to them, a little or not at all. The second step is that the children write down conclusions and agreements in order to have something they can fall back on.
Teachers can use this method as substitution of the Checkpoint and Looking back and Classroom reflection. The content is similar, but more game like. With this method it is easier to put a focus in the reflection on a specific element of the process. It is also easier to use the method multiple times during the process and let a group reflect, because they can use the same card set multiple times.

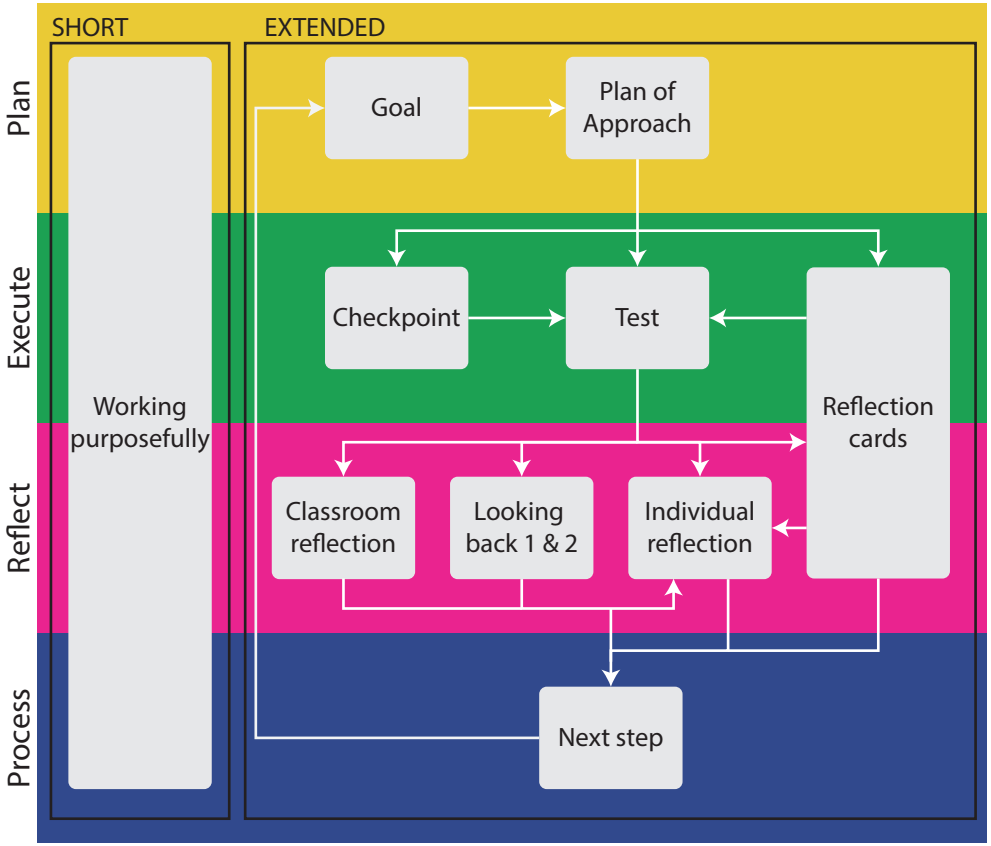


Figure 57. *Overview of elements of the final design of Iteration tool*

Individual reflection
This sheet lets children individually reflect on what they personally have done, learned and possibly still want to learn.
Teachers can use this method in the Reflect stage next to or instead of the other three reflection methods. By using this method teachers can find out which skills need to be practised.

Recurring elements on the worksheets

Figure 58 shows the recurring elements of the worksheets of the Iteration tool.

All the sheets have a main colour which refers to the stage of the iteration model it belongs. The default of the design is in colour to make the sheets more attractive for children. Next to the colour all worksheets also have an icon that refers to a stage of the iteration model. When a teacher decides to print the worksheets in black and white, the gradient of the stages still differ (see Figure 56 on page 78) but it might be harder to distinguish the gradients and link them to a stage when you only see the worksheet. By adding an icon it is also in black and white clear to which stage a worksheet belongs.

The borders of the frames are drawn by hand in order to make it look more playful and inviting to fill in. With straight lines the worksheets would look very formal.

In the coloured bar at the top there is a white box in which the groups can write their (group) name. This has to be white to be able to (easily) write on it.

The numbers on the worksheets indicate the different steps that need to be taken.

The worksheets have lines to write on and white spaces. The lines are meant to give the children some guidance in writing, but the sheets are not full with lines to also invite the children to draw if they feel more comfortable drawing.

The titles are in Amatic SC and the main text in Josefin Sans, just like the other worksheets of Your Turn.

The worksheets have drawn figures on it. This element is added because it is a recurring element in the Your Turn worksheets. The Iteration tool is an addition to what tools Your Turn already provides and by adding the figures to the Iteration tool there is a connection between the visual designs of the tools.

Lastly, on the bottom Your Turn sheets always have the Your Turn logo, website and title of the worksheet.

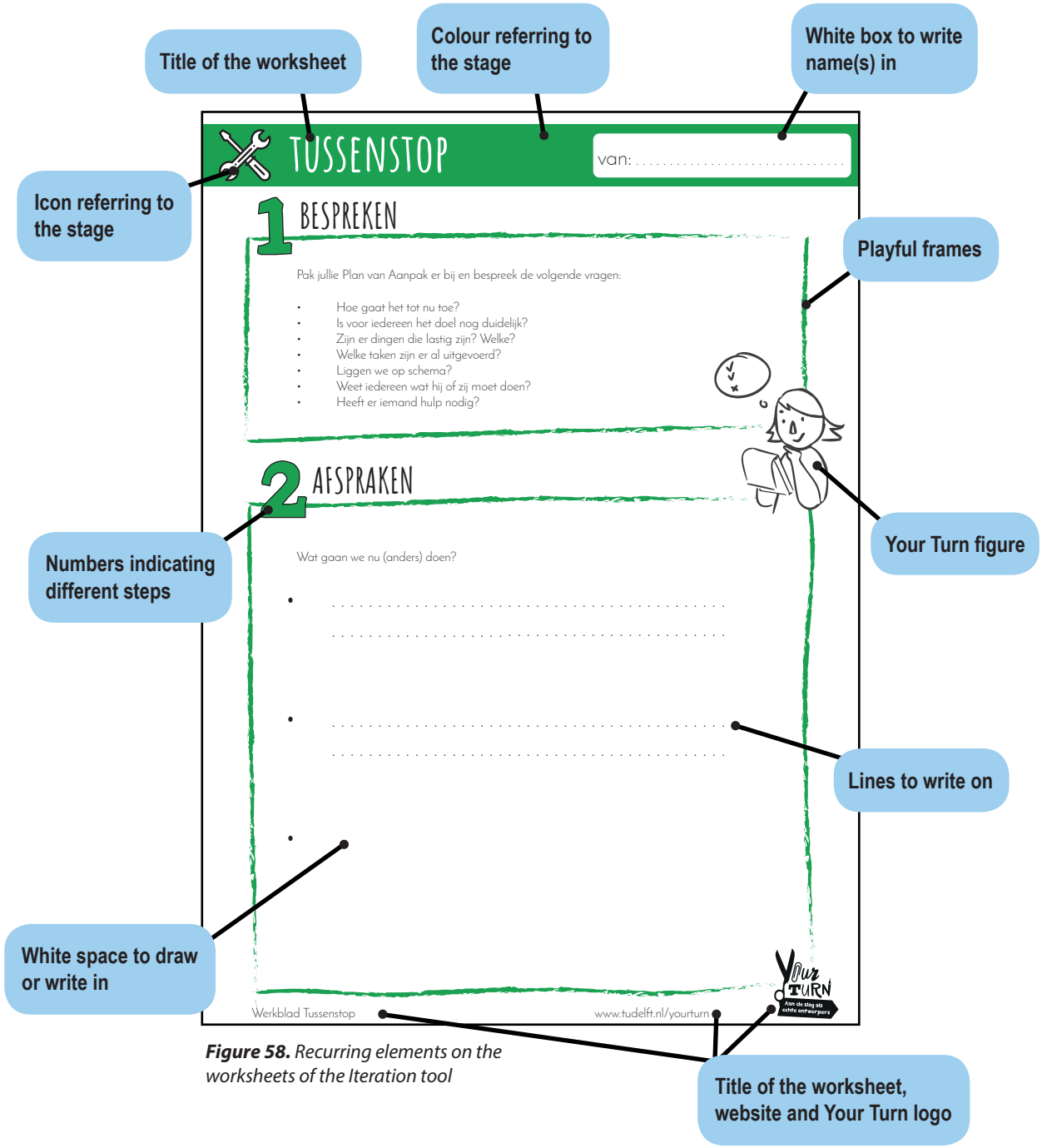


Figure 58. *Recurring elements on the worksheets of the Iteration tool*

All worksheets

Working purposefully

Figure 59 shows the final design of Working purposefully. Step 1 had two questions about formulating the goal and for some children it was the same question. Therefore one question is removed and a sentence is added to make the group aware of what the impact of their choice is on what they will prototype. Step 5 is now a hypothetical question: What if you would continue? What would be your next step? This way teachers can use the worksheet to teach children to purposefully prototype, but could still continue if that is desired.

Goal & Plan of Approach

Figure 60 shows the final design of Goal and Figure 61 of Plan of Approach. The worksheet Plan of Approach used to be A3 size, but in order to make it easier to combine the sheets in a folder all the sheets of the Extended version A4 size. The first part of Plan of Approach was about the goal and since one of the questions on the Goal worksheet was redundant, there was room to move that part to the Goal sheet. This way the steps of Plan of Approach fit on A4.

You could argue that with only the 'make your own goal-card' the children are forced to draw. But the test showed children either write and draw or write their goal-card in the box, so they use it the way that works best for them.

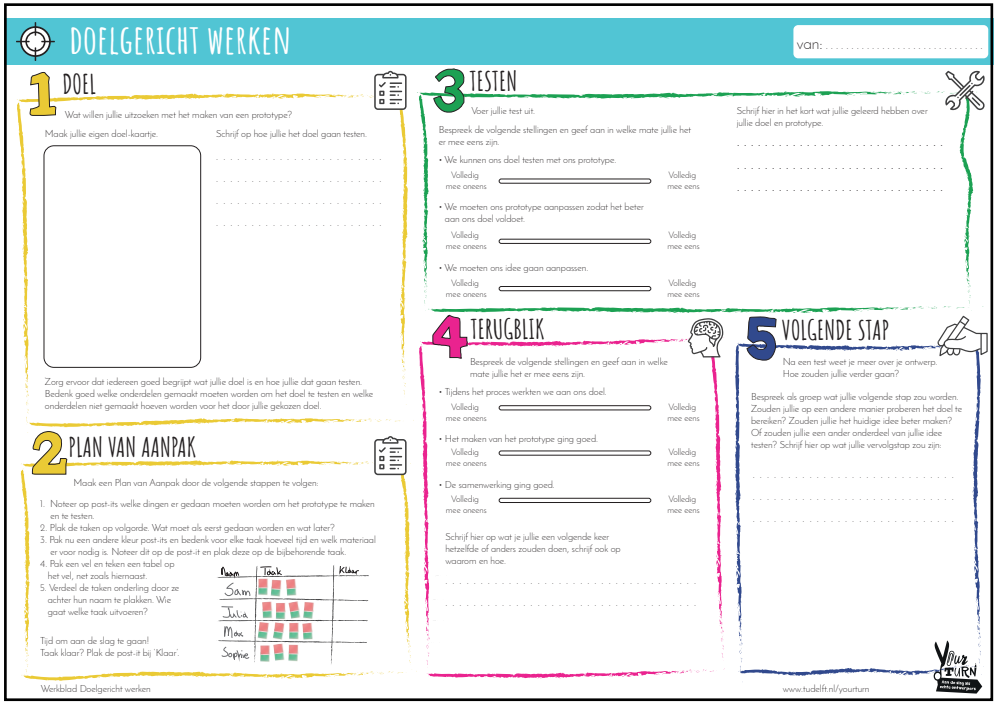


Figure 59. *Final design Working purposefully*

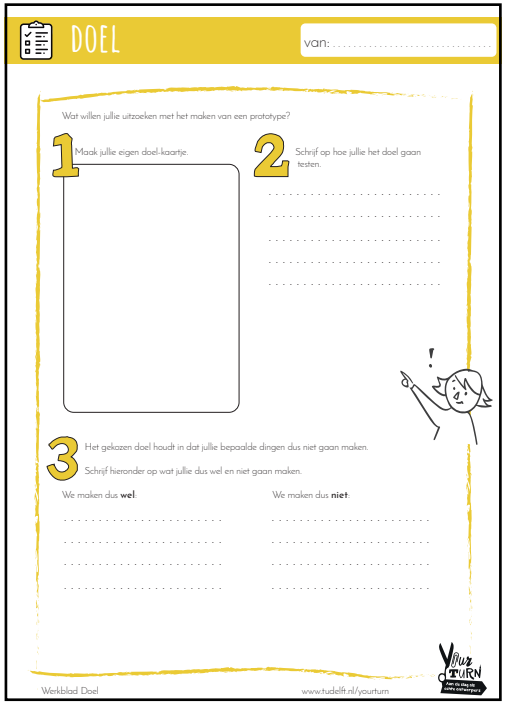


Figure 60. *Final design Goal*

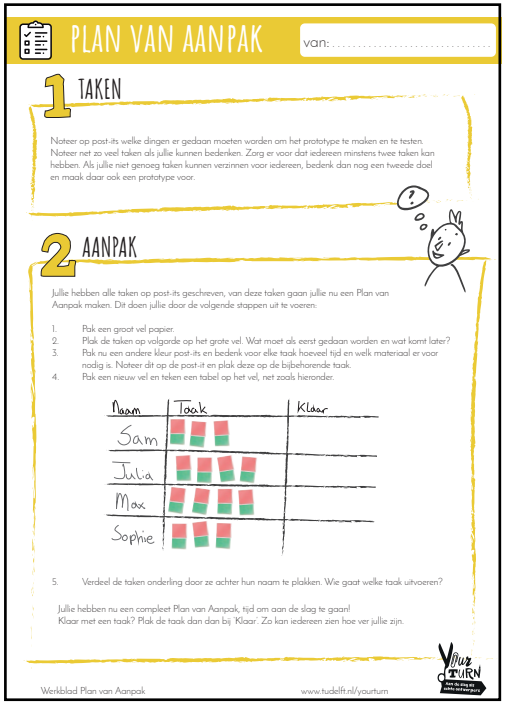


Figure 61. *Final design Plan of Approach*

Checkpoint

Figure 62 shows the final design of Checkpoint. The title of this worksheet changed since almost all children that participated in the test do not know the meaning of 'checkpoint'. They do know the word 'tussenstop', which is checkpoint translated In Dutch.

Figure 62. *Final design Checkpoint*

Test

Figure 63 shows the final design of Test. This worksheet only has adjustments that are made to all worksheets.

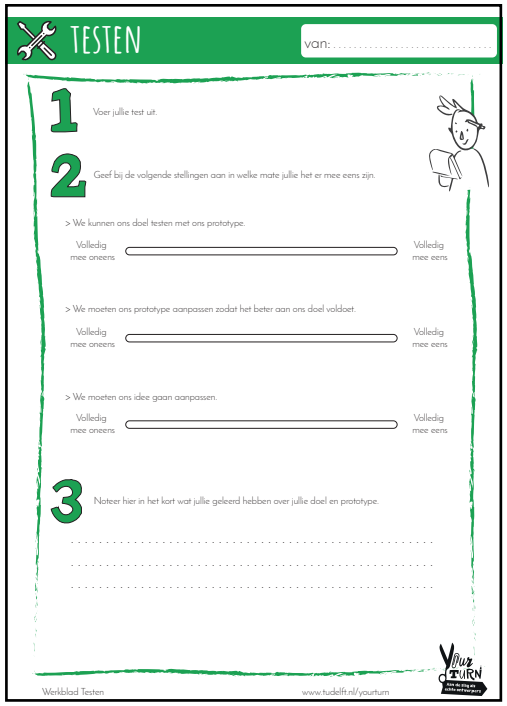


Figure 63. *Final design Test*

Classroom reflection

Figure 64 shows the first slide and a statement slide of the final design of Classroom reflection. The content of the Classroom reflection did not change compared to the version before the tests. The final design uses the same type of boxes as used in the other elements of the Iteration tool.

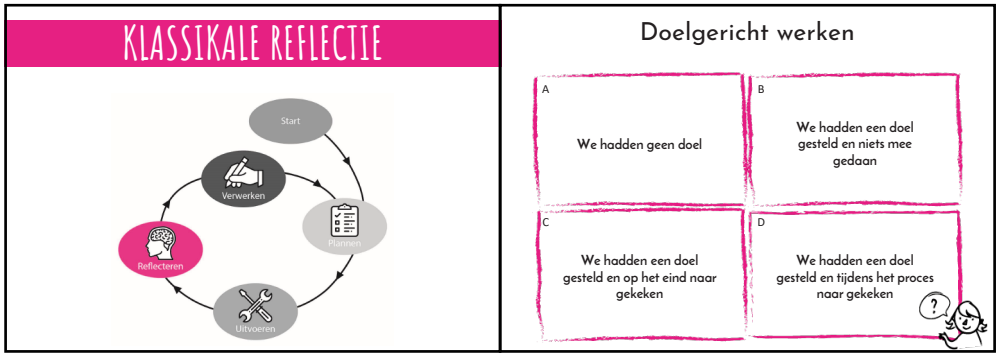


Figure 64. *Final design Classroom reflection*

Looking back

Figure 65 and Figure 66 show the final design of Looking back. The content is spread over two A4s in order to easily combine the sheets in a folder.

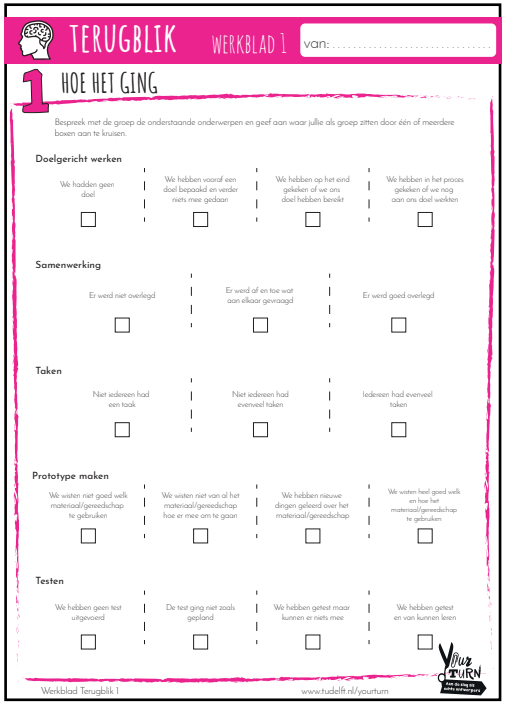


Figure 65. *Final design Looking back sheet 1*

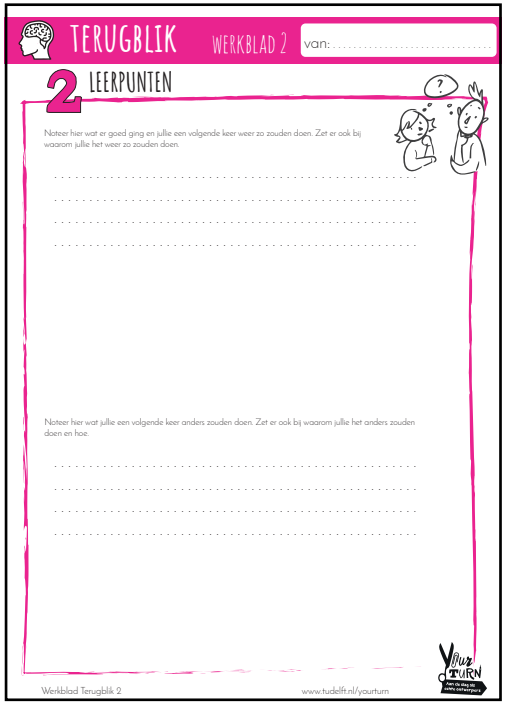


Figure 66. *Final design Looking back sheet 2*

Reflection cards

Figure 67, Figure 68 and Figure 69 show the final design of Reflection cards. The borders of the statement cards are now green and pink, the same colours as the stages in which the cards can be used. The cards used to have two rows for answers, Checkpoint and Looking back. It now has only one row, allowing teachers to implement it multiple times in a stage if that is desired. They could either use pencil and erase previous answers or use different colours each time. The titles of the sheets for writing down their conclusions is changed to Reflection. This way all worksheets have their own unique names.

Figure 67. *Final design Reflection cards*

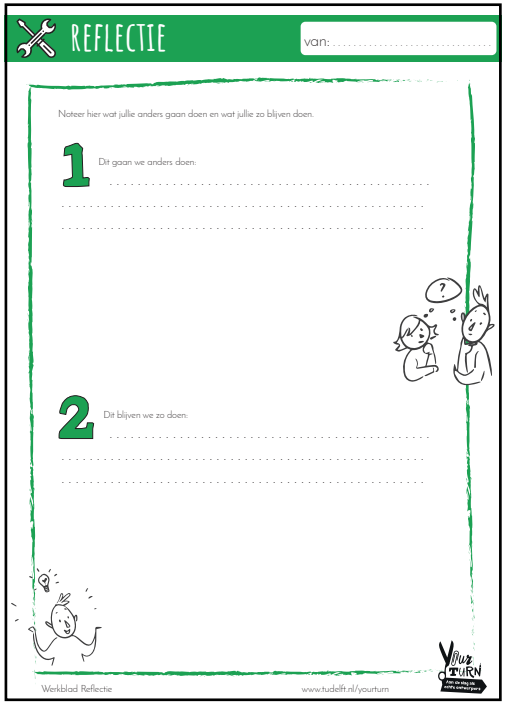


Figure 68. *Final design Reflection cards*

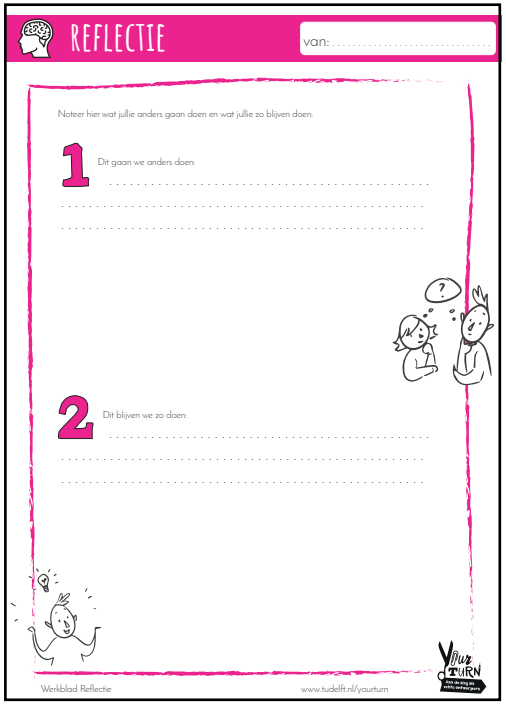


Figure 69. *Final design Reflection cards*

Individual reflection

Figure 70 shows the final design of Individual reflection. This used to be Looking back Worksheet 2 but is an individual reflection which can be done after or instead of all the other group reflection methods. Therefore, this worksheet now has its own title and is presented as separate reflection method.

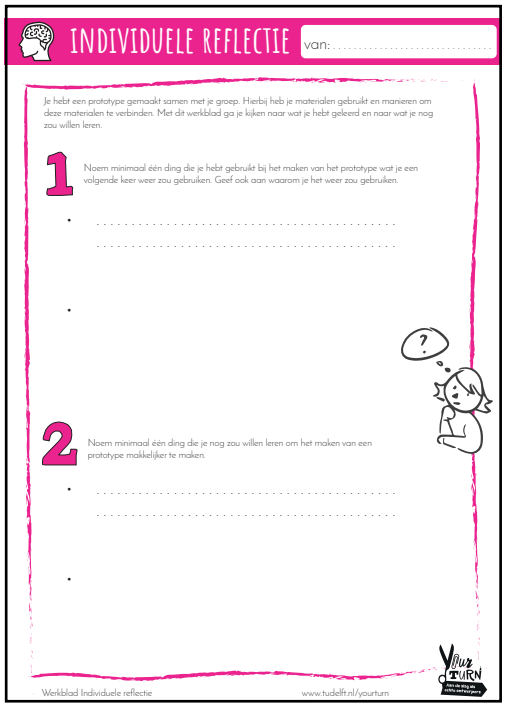


Figure 70. *Final design Individual reflection*

Next step

Figure 71 shows the final design of Next step. This worksheet replaces New goal. New goal was content wise and visually the same as Goal. This caused confusion among the children, they had the feeling they already did that step and did not know how to look at it as a new step.

Next step provides the children with four possible options after they did their test. They can either try to reach the same goal but in a different way, try to optimise their prototype, have a different goal for the same part of their design or prototype a different part of their design. By providing these options the children will know better what directions they can go after they have tested their prototype.

Another reason to adjust the New goal to Next step is because there was not a worksheet for the fourth stage of the iteration model, meaning no guidance in how to go through that stage. Now all the stages of the iteration model are covered and a new iteration would start with the Goal worksheet.

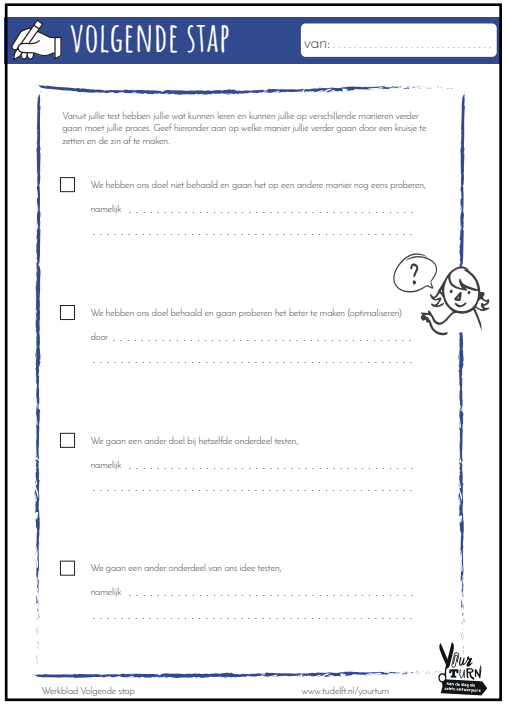


Figure 71. *Final design Next step*

12.6 Implementation

Part of Your Turn

At the moment Your Turn has several tools available for the different phases of the design cycle. For prototyping they have one worksheet for creating a test plan. The Skill tool, Prototype-discussion-game and Iteration tool can fill the gap and provide tools for prototyping.
By implementing the tools in Your Turn you already reach the teachers that make use of the Your Turn tools.
Next year Science Hub TU Delft is giving guest lectures at PABOs. At the moment the students get some classes about the design cycle, but not many. It is ideal to mention and present all the tools in these guest lectures. With the Info booklet the students will learn what the importance and role of prototyping in a design process is and by presenting the Skill tool, Prototype-discussion-game and Iteration tools they get familiar with ways to implement prototyping in lessons. PABO students are the teachers of the future, so when it is part of their education they can broaden their knowledge and apply it in their lessons.
All tools of Your Turn have a default lay-out for the explanation of the tools. In Appendix 9 you can find the explanations of the Skill tool, Prototype-discussion-game and Iteration tool. The explanations refer to the other methods to make teachers aware of the available methods and value they have.

Skill tool: Learning practical, technical making skills needed for prototyping.
Prototype-discussion-game: Learning about different goals prototypes can have.
Iteration tool – Short: Learning to purposefully prototype.
Iteration tool – Extended: Iterating by making multiple prototypes.

Format of the tools

The Skill tool, Prototype-discussion-game and Iteration tool are designed to be used as paper sheets. This is in line with the other tools of Your Turn.
For the Iteration tool worksheets on paper work best since this allows a group to easily share, see and discuss the worksheets.
The Skill tool could also be used from a screen, one of the participants in the test did this, but for sharing it is easier to have the cards printed.
The Info booklet can either be read on a device or on paper.

Further development

The Prototype-discussion-game can be offered to teachers. The Skill tool can be offered once all the skills have been checked and executed by children. The Short version of the Iteration tool could already be offered. Before offering the Extended version of the Iteration tool it is recommended to first test the tool in one or two classes in a project where they have to make multiple prototypes in a row. With the knowledge gained from this test the tool can either be implemented or improved on and then be implemented.

Conferences

Conferences about (maker) education are also good places to present the tools. Fablearn Conference would be a good place to present the Skill tool to provide a concrete example of how to implement maker education in your lessons.

Implementation in secondary education

The tools are developed for primary education, but could also be implemented or translated to secondary education. The skills in the Skill tool are too simple for secondary education, but you could transform the skill cards to skills that are interesting for secondary education. Interesting skills for secondary education are: (jig)sawing, laser cutting. 3D printing and drilling. This tool would be interesting for students of 'Technasium' (havo/vwo), 'Technologie & Toepassing' (vmbo gl/tl) and 'Techniek' (all levels).
The Prototype-discussion-game and the Short version of the Iteration tool could be used to introduce the students to purposefully prototyping. These are mainly interesting for students of 'Technasium' and 'Technologie & Toepassing'.
In order to know if the Extended version of the Iteration tool is interesting for secondary education, more research needs to be done on the needs and goals of prototyping and iterating in secondary education.

13. Recommendations

This chapter describes several recommendations for further development of the tools.

13.1 Info booklet

I would recommend to test the Info booklet with teachers that are about to prepare a design assignment in class. This way you can test whether the booklet is not only informative but also supporting the teachers in preparing and facilitating in the design process.

It could be valuable to explore the option of adding real life scenarios from which the teachers can learn. This can be video fragments of children working on their design assignment with a voice-over indicating important things to notice and takeaways. Seeing real life scenarios can help teachers in preparing for their own classes and allows them to get familiar with what the process of a group can look like.

It might also be valuable to look into making more info booklets on different subjects. Another info booklet could be about diverging and converging in a design process.

13.2 Skill tool and Iteration tool

The Skill tool and Iteration tool have been tested in a different setting than the setting it is designed for. Both tools are designed for primary education to be used in class. In this project the tool could not be tested in the desired environment. It is recommended to test the tool in the real setting.

The Skill tool and Iteration tool have been tested separately. The purpose of the Skill tool is to improve the making skills of children and therefore make creating prototypes easier for them. In order to say whether the Skill tool contributes and indeed makes creating prototypes easier, the Skill tool and Iteration tool have to be tested together.

13.3 Skill tool

Selection of skills

In this project not all skill cards have been tested by children. In order to find out whether all the skills are appropriate for children, they should all be tested.

In order to make the skill set more complete, I would recommend to look into adding a skill card about soldering. This skill would be a good addition and creates new opportunities for children to prototype, since it allows them to use electrical elements in their prototypes. I would also recommend to add skills involving paper, since it is a commonly used material at primary school.

I would also recommend to look into expanding the set with skill cards focussed on certain properties of materials and constructions. A good example would be 'Stabiele vormen' from the teaching model 'Biomedisch Ontwerpen' *(Biomedisch Ontwerpen)*. Via this assignment children will learn about properties of different shapes, which they can use while prototyping. 'Overbruggen' from 'Biomedisch Ontwerpen' would also be a good example. Via this assignment children learn about properties of a piece of paper and how you can influence them. Another interesting subject for a skill card might be bending cardboard versus having 90 degree edges.

Instruction video

The participants that tested the Skill tool both mentioned that they preferred instructions on paper over an instruction video. It could be that it is a coincidence that both preferred paper, so it advisable to check with more children what they think about an instruction video. It could be that children who struggle with word processing (e.g. dyslexia), prefer an instruction video.

Adjusted instructions

The instructions on the 'Deforming iron wire' card were not clear during the test. In the final design the steps are made more elaborate and it has to be tested whether the instructions are clear enough like this. It could be that when children learn a new practise, it is needed to have an instruction video to better show how to handle a tool and that paper is preferred the moment they already know how to handle the tools.

During the test the last step has been adjusted. In order to get a better understanding whether these instructions are enough to help the children execute the last step, the tool as to be tested with a bigger group.

13.4 Prototype-discussion-game

Self-explanatory

In the test there was one group of children that executed the assignment without the presence of their parents, they did not manage to play the game. In order to find out whether the instructions should be adjusted, I would recommend to test the game with multiple groups without the help of an adult.

Stimulating discussion

In most groups there was still not much discussion while deciding which goal-card fitted best with the prototype-card. In all the groups that played the game there was an age difference between the children. I would recommend to test the game with peers, to see whether that allows children to have a discussion on their level.

I would also recommend to test the game in a group of 3-4 children, this could also influence and stimulate a discussion since there are more opinions involved.

13.5 Iteration tool

Order of use

I recommend to first use the Short version of the Iteration tool. This allows the children to get to know the steps they need to take and I believe this would make using the separate sheets later easier and clearer, since they are already familiar with the overall process. In order to see whether my assumption is correct this will need to be tested. A way to test this would be by having a group using the Short version before they would use the Extended version, to see whether they are able to keep an overview during the second assignment.

The test shows that children struggle with reflecting. I would recommend to first use the Classroom reflection of the Iteration tool. This way the teacher can help and guide the children through their thinking process and make them aware of how they can reflect and learn from it. The assumption is that this will help the children in reflecting on their own afterwards. This is something which should be tested.

Using the tool several times

One of the children mentioned that they think using the tool again would be easier. I would recommend to have a group use the tool multiple times, to find out what being familiar with the materials means for the value and implementation of the tool.

Type of assignment

A goal of the Iteration tool is to stimulate children in making multiple prototypes in their design process. I would recommend to test the Iteration tool in an assignment where the children have to make multiple prototypes and have them use the Iteration tool in their process. It will be interesting to see whether the groups really iterate on their idea if they have to make multiple prototypes or whether they would just do the same thing twice.

I would recommend to test the Iteration tool with a different kind of assignment than used in the test of this project. The assignment in this project had a clear given, testable goal and was straightforward. It would be interesting to see whether children would manage to come up with specific (small) goals for their prototype in a more open assignment.

Length of assignment

In the test the ratio between executing the steps and filling in the worksheets was out of proportion. I would recommend to test the Extended version of the Iteration tool in a bigger project that takes more time to execute. Is the ratio executing the steps and filling in the sheets better in a bigger assignment? And does the time to fill in the Short version of the Iteration tool match with smaller assignments?

The test shows that the checkpoint did not always have an added value to the process of the children. This could have to do with the time spent on making the prototype and it being without breaks. I would recommend to test the value of a checkpoint when the time spent on making the prototype is long (≥ 1 hour) and when it is spread over several moments, in order to give recommendations to teachers on how to implement it in their class.

Group size

For some groups the work of filing in all the worksheets was perceived as a lot of work. I would recommend to test the Extended version with bigger groups (3-4 children), to find out whether the work is still perceived as a lot, or if it makes a difference when you do not have to fill in all the sheets and can divide the work better, or if it would still be only one child filling in all the sheets.

Homogeneous groups in terms of age

The Iteration tool is mainly tested by groups of children with different ages. I would recommend to test the tool in homogeneous groups in terms of age to find out if the younger children (< 9 years) would still be able to find a way to use the worksheets with or without help from a teacher, or if the sheets will be too hard for them and in this form only works for 9-12 years old. I would also recommend to test the tool in a homogeneous group in terms of age with older children (group 6-8) to find out how they would use the worksheets and how it influences their group dynamics. Maybe there is more conflict because they all can express themselves better, or will it be easier because there is a chance that there is always one that understands a worksheet and can explain it to the others.

Plan of approach

Creating a plan of approach was for most groups a meaningful step. I would recommend to test whether a plan of approach has a different role in bigger or even smaller assignments. I would also recommend to test what the role is of a plan of approach is when it is used in a bigger group (3-4 children).

Setting a new goal

The New goal worksheet is adjusted based on the findings in the test and transformed to the Next step worksheet. I would recommend to test whether this new form helps the children in deciding on of what step should be next and in understanding the purpose of setting a next step with a new goal.

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Figures

Figure 4: Wetenschapsknooppunten Zuid-Holland. Retrieved on 07-01-2020 from https://www.wetenschapsknooppuntzh.nl/

Figure 5: SLO. (2019). In 2020 op alle basisscholen wetenschap & technologie: Bent u er klaar voor? Retrieved on 07-01-2020 from https://slo.nl/publish/pages/4778/in-2020-op-alle-basisscholen-wetenschap-en-technologie.pdf

Figure 7: SLO. (2019). 21e-eeuwse vaardigheden. Retrieved on 07-01-2020 from https://slo.nl/thema/meer/21e-eeuwsevaardigheden/

Figure 13: The design cycle: Wetenschapsknooppunten Zuid-Holland. Retrieved on 07-01-2020 from https://www.wetenschapsknooppuntzh.nl/

Figure 14: McLeod, S. A. (2013). Kolb - Learning Styles. Retrieved from www.simplypsychology.org/learning-kolb.html

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