

# Collaborative Learning in Primary School Mathematics

Enabling learning together through a mediating, digital interface

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Gothenburg, Sweden, 2020

[www.chalmers.se](http://www.chalmers.se)



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Print: Chalmers digitaltryck





# Abstract

In this thesis, it is explored how collaboration can be applied in primary school mathematics. Eeducation Albert AB, the company which this thesis is written in cooperation with, are interested in collaborative learning as it has shown to deepen knowledge and improve the social environment.

A literature study was conducted on the topics; educational science, mathematics, collaborative learning, digital tools in the classroom environment, design for children and activity theory. This was done to prepare the authors for the user study and to compare how education is conducted with theory on how education should be conducted. Collaboration was reflected in the outcome and throughout the process by involving pupils in four phases of the design process. The pupils contributed through observations and interviews, by creating content, and evaluating early hypotheses, as well as initial concepts. Furthermore, teachers and experts were interviewed to gain their point of view on important factors in learning and collaboration.

Guidelines on how to design a digital interface that mediates collaborative learning in the classroom were created based on the results of the literature study and the user studies. Twelve educational guidelines and nine esthetical guidelines were created. Out of these, the ones that contribute most to collaboration are the guidelines regarding communicating and explaining, promoting inclusion, and encouraging reflection. Based on the guidelines, an illustrative concept was designed. This concept is designed to be colourful and interesting to pupils while focusing on creating educational benefits, for example by including both open- and close-ended questions with visual support for discussion. The illustrative concept is designed to be part of a fully digital mathematics book.

**Keywords:** collaboration, mathematics, primary school, education, digital interface, design for children, participatory session



# Acknowledgement

We would like to thank all of the teachers and pupils that have been a part of this thesis. Thank you for allowing us to participate in your classes and conduct our user studies. It has been of great importance to us that collaboration should be reflected throughout the process by involving pupils and because of your welcoming and inspiring attitudes you have made it possible. Your positivity, curiousness and creativity has inspired us. Without you we would never have written a thesis which includes the sentence: outer space laser fight between alien crabs.

We would also like to thank Eeducation Albert for the opportunity to write our thesis with you. A special thank you to our supervisor at Eeducation Albert, Sebastian Christ, who has enabled us to write a thesis on a topic that has been immensely inspiring, and for encouraging and trusting us in our explorative and iterative process.

Continuing, we would like to thank Anneli Selvefors and Pontus Wallgren for sharing their knowledge and expertise with us on activity theory and user studies. Furthermore, we would like to thank Damiano Ognissanti and Johanna Tholén for taking their time to talk to us about education and their work. Kristoffer Hewitt, thank you, for helping us with language when we have needed feedback or translations.

Thank you to Oskar Rexfelt for being the examiner of this thesis and for giving us valuable advice on how to approach the topic and research questions. Thank you for giving us feedback and helping us see the holistic view on the thesis.

Finally, to our supervisor, Fredrick Ekman. Thank you for advice and support in moving the process forward. You have encouraged us throughout the project, when we thought we would have to cancel our user studies due to Covid-19, when we have visited classes to evaluate our designs and on countless other occasions. Thank you for all the valuable time you have spent on this thesis, for your constructive feedback, and rewarding discussions.

  
\_\_\_\_\_  
Gabriella Hammarlund

  
\_\_\_\_\_  
Klara Albinsson



# Terminology

## **Activity**

- A person's doings directed towards an object formed by the person's motive or motives, mediated by a tool.

## **Artefact**

- An object created by humans.

## **Educational method**

- Term used for the methods that are applied in learning material, for example repetition.

## **GDPR**

- Abbreviation for The General Data Protection Regulation, which is a regulation on processing personal data.

## **Idiom**

- A characteristic visual style and expression.

## **Object**

- Formed by the motives of a person and acted upon to achieve an outcome within an activity.

## **Learning approach**

- What approach the pupils use to learn based on their preferred senses, an example of this could be by rhythm.

## **Learning techniques**

- Techniques used by the pupils to learn, example of this could be calculating on their fingers or using a ruler to count.

## **Triangulate**

- To use different methods to ensure data quality by being able to compare and combine data sets.

## **Primary school**

- In this thesis primary school will be used to describe the pupils of year 1 to 3 (age 7-9).

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# 1. Introduction

The amount of apps designed for children is constantly increasing and the apps that allow children to practice mathematics are no exception. These apps are used in schools, but do not appear to be designed for this purpose and it is therefore debatable if they are adequate for usage in this context.

The curriculum is a document that is changing to correspond to new demands of knowledge in the ever developing society (Lärarens handbok, 2018, p.5-15). Corresponding to this, the Swedish curriculum of the academic year 2018/2019 has been revised to include that pupils should develop adequate digital skills to be able to navigate the ongoing digitalisation of society. This has led to schools providing pupils with tablets or laptops where they can practice both their digital skills but also different subjects such as Swedish and mathematics.

Education is an important part of every child's life, and Swedish children are required by law to go to school, starting with preschool until they have finished year nine. Among other subjects, the children learn mathematics which they will encounter in many situations throughout their life. It is therefore of great importance that the education is of high quality and gives them the necessary prerequisites for handling everyday life as adults and continuing on to further education. Collaborative learning is a way to create deeper learning as the pupils are involved in discussions and are interacting with each other (Baturay and Toker, 2019). It is therefore of interest to explore how collaborative learning can be implemented in mathematics.

The education system in Sweden regulates both the subjects that the education contains and social aspects such as compassion and understanding of others. Successful collaborative learning has proven to positively impact the classroom environment and create a sense of community (Hamutoglu, Gemikonakli, and Gezgin 2019). This further implies the relevance of establishing collaborative learning in education.

A digital interface that encourages pupils to collaboratively learn mathematics in their classroom could therefore positively affect the individual pupils' mathematical knowledge, their digital skills, their social skills, and the whole classroom environment.

## 1.1 The Company & Problem Statement

Eeducation Albert AB is a company that provides digital products for learning and practicing mathematics for children in the age of three to fifteen. Their current products are two apps, junior and senior, divided into two different year groups that follow the Swedish curriculum. The products are currently not used in school, but rather work as a tool to enhance mathematical knowledge in private usage outside of the classroom. A monthly subscription allows users to download the applications to a smartphone or tablet.

As a separate project to their current products, Education Albert wants to explore the possibility of creating a digital tool that can be used in the classroom for pupils to collaborate when learning mathematics. They find that the current way of learning mathematics is often individual although research has shown that pupils benefit from collaborating with each other (Baturay & Toker, 2019).

## **1.2 Purpose**

The purpose of the project is to understand what factors enable pupils in primary school to learn mathematics collaboratively in the classroom in a learner to learner situation. Furthermore, research will be conducted to investigate how this can be enhanced through a digital interface.

## **1.3 Aim**

The aim is to create guidelines and design a concept, based upon those guidelines, for a digital interface that enables collaborative learning of mathematics in the classroom for pupils in primary school.

### **Research Questions**

- What are the main principles in education science within mathematics and how are they currently applied?
- How does learner to learner collaboration affect learning outcomes and to what extent and in what way is it practiced today?
- How could a digital interface be designed to account for the mathematical education principles and enhance the collaborative learning in a Swedish primary school environment?

## **1.4 Demarcations**

The primary users are defined as pupils in Swedish primary schools in year one to three and the concept that will be developed should work in their classroom. The secondary users are defined as teachers and therefore, the main part of the user study will be focused on understanding the pupils and their needs. The teacher plays a significant role in the possibility for the primary schools to implement a concept like the one described in this report and therefore their perspective is taken into account but not analysed in depth. Any technology used for the concept should be available for implementation during the year 2021.

The process will result in guidelines based on existing theory and the findings in the user studies. The guidelines will in turn be used to develop a prototype used for testing functions and exploring interactions, both between pupils and between pupils and the interface. The authors do not aim to create a product that is immediately ready for implementation, but rather a concept that functions as a foundation for further development. The concept will serve as an example of how collaborative principles can be designed in a digital interface. The digital interface that is described refers to what the pupils see on the screen when using the tool.

The design phase will result in a concept for a collaborative complement to a digital mathematics book. However, the book doesn't exist yet and is unlikely to be designed during the time span of this project. Therefore, the research and design will be based on current physical mathematics books, following the Swedish curriculum and syllabus. Furthermore, the concept will be adjusted to the education and the educational environment of Swedish primary schools.

This thesis was written during the outbreak of COVID-19, which has impacted certain parts of the data collection. The Swedish schools were not closed during the outbreak and the authors have therefore been able to conduct the most important user studies in context. However, the authors were supposed to observe two mathematical workshops with pupils at the International Science Festival Gothenburg and attend a teachers conference. Both of these were cancelled. Throughout the process the authors carefully monitored the development of the outbreak and followed the regulations from the Public Health Agency of Sweden.

## **1.5 Process**

The process of this thesis was divided into five phases. These phases were iterative, where insights were drawn and revisited in order to ensure quality of the presented results. To initiate the process, phase one consisted of a literature study where theoretical data was gathered. Phase two, user studies in context, consisted of further immersion in the subject through user studies. Continuing, phase three describes the participatory sessions with pupils. The fourth phase included development of guidelines, concept prototypes and evaluation of idioms and assignments by pupils. The fifth phase consisted of development of two concepts and summatively evaluating these. Finally, an illustrative concept was developed. The content of each phase is described in further detail on the following page.

**1 Literature study**

Academic papers

School law

Books

Analysis

**2 User studies in context**

Analysis

Interviews with experts

Interviews with teachers

Interviews with pupils

Observation

**3 Participatory session**

Ideation

Prototype construction

Session in context

Analysis

**4 Formative evaluation**

Analysis

Evaluate in context

Material construction

Ideation

**5 Summative evaluation**

Creation of guidelines

Ideation

Prototype creation

Evaluate in context

Analysis

Illustrative concept

## **1.6 Disposition of Report**

- Chapter 1 – Introduction,  
provides an introduction to the topic, as well as the purpose, aim, and research questions to be answered.
- Chapter 2 – Frame of Reference,  
presents the theory that has been gathered in the literature study.
- Chapter 3 – Literature Study,  
explains how the theory in the Frame of Reference was collected.
- Chapter 4 – User Studies in Context,  
explains how observations and interviews were conducted and what results were yielded.
- Chapter 5 – Participatory Sessions with Pupils,  
gives insights into how the participatory session was conducted and presents results from it.
- Chapter 6 – Formative Evaluation of Idioms and Assignments,  
evaluates initial ideas and the results from said evaluation are presented.
- Chapter 7 – Guidelines,  
presents guidelines based on the insights from the research in the previous chapters.
- Chapter 8 – Initial Concept Development,  
presents two initial concepts.
- Chapter 9 – Summative Evaluation of Initial Concepts,  
evaluates the two concepts and presents the results from this evaluation.
- Chapter 10 – Illustrative Concept,  
an illustrative concept based on the guidelines is presented.
- Chapter 11 – General Discussion,  
consists of a discussion about the process, the illustrative concept, and future work.
- Chapter 12 – Conclusion,  
explains the main conclusions drawn in the thesis.

## **1.7 Ethical Considerations**

This thesis is concerned with user involvement, societal, ecological, and ethical considerations.

### **1.7.1 User Involvement**

As the process of this thesis includes involving teachers and pupils through user studies it is important that personal data is handled according to GDPR or that participation is anonymous. Furthermore, when working with children it is of great importance that there are clear agreements with schools. Participation outside of lesson time will be voluntary and all participants can withdraw at any time.

When developing the digital interface pupils will be engaged in the design process as the collaborative approach should be reflected in both the process and the outcome. By involving pupils through participatory sessions and evaluations the authors will be further made aware of, and attentive to, the needs and desires of the pupils.

### **1.7.2 Societal**

As education is one of the UN Sustainable Development Goals, the thesis project relates to social sustainability (United Nations, retrieved 2020). Out of the 17 sustainable development goals, especially number four which is phrased as "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" is relevant to this thesis. By applying collaborative learning in mathematics the aim is to deepen and improve the learning and thus achieve a higher quality education. Further, the aim is to encourage pupils of different levels to collaborate with each other and thus working for a more inclusive education. Research has shown that pupils with learning difficulties benefit from inclusion both from a learning perspective and from a social point of view (Bähr, 2015, p.17).

### **1.7.3 Ecological**

The authors of this report recognise the importance of ecological sustainability. However, within the scope of this thesis there is little room for affecting the ecological impact of the concept as it is already set to be digital. The benefit of designing a digital concept is that there is no negative environmental impact from paper manufacturing or printing. The observation has shown that the mathematics books used in primary school are designed for singular use since the answers of the pupils should be written in the book. A digital mathematics book would also have negative environmental effects since it requires both a product such as tablet and server capacity. To exclude the digital products such as tablets from schools could however be seen as a conflicting sustainable goal between the ecological and societal. The Swedish curriculum includes that the pupils should develop adequate digital skills to navigate the digitalised society (Lärarens handbok, 2018, p.5-15). If the digital tools were excluded it could in turn result in that the pupils from low socioeconomic status would have less digital skills.

#### **1.7.4 Ethical**

The concept has to allow for a type of collaboration that enhances learning without compromising the individual pupil's education. Thus, not only benefit one type of individual or one group of students. Therefore, the design needs to take into account that pupils may have achieved varying levels of skill. Continuing, the concept should not encourage negative competition between students or create new opportunities for exclusion.



**Frame of reference**

**Learning & teaching**

**Mathematics**

**Collaborative Learning**

**Designing for children**

**Digitalisation in classroom**

**Swedish national steering documents**

**Activity theory**

## 2. Frame of Reference

This chapter will give a theoretical background to the key topics introduced in this thesis. These topics include learning & teaching, mathematics, collaborative learning, designing for children, digitalisation in classroom, Swedish national steering documents and activity theory. The chapters below are the result from the literature study that was conducted (see chapter 3).

### 2.1 Learning & Teaching

Pedagogical processes include upbringing, teaching and education and the activities that are included in these processes can be defined as support for learning (Nesse, 2020a). As a field of study, pedagogical processes are concerned with exchange of thoughts, knowledge, and discussion. Nesse (2020b) states that to learn is to gain knowledge or skill in a field so that a certain expertise is achieved. Further, they explain that examples of such can be learning to read or to operate a vehicle. Dysthe (2003, p. 7) analyses learning from a socio-cultural perspective which is based on that learning is fundamentally a social activity, where knowledge is gained through working together in a context.

#### 2.1.1 Aspects of Learning

From a socio-cultural perspective there are six main aspects of learning (Dysthe, 2003, p. 41- 50). The main aspects are that learning is; situated, social, distributed, mediated, relies heavily on language, and the participation in communities of practice. The first aspect refers to that learning is situated in physical and social contexts where the student interacts with people, tools (for example digital technology), and representation systems (for example symbols) in their surroundings. Continuing to the second, the social aspect takes into account both the history and the cultural context as the knowledge has been built on insights formed in society over time. The third aspect, distribution, is explained as that a group of people will have different skills and knowledge that together can create a more complete understanding. Learning is mediated by artefacts, according to the fourth aspect. This means that tools can be used to support learning in different ways, for example by providing information or promoting organisation to structure the learning process. The fifth aspect is language which is defined as a link between culture, interaction and thoughts (Säljö, 2000, in Dysthe, 2003, p. 41-50). Importance is placed on this as communication is viewed as a foundation for all learning and development. Dysthe (2003 p. 41-50) further states that children learn through listening, talking, copying and cooperating with others, and that language provides a link between communication and thinking. Finally, the sixth aspect is based on that learning happens everywhere and at all times, and that initially the learner is in the outskirts of the participation community but moves inwards as the learning progresses.

#### 2.1.2 Competences of the Teacher

To understand the education situation the didactic triangle offers a framework by describing the relationship between three categories or perspectives; teacher, learner, and subject (von Oettingen, 2018, p.55-115). Even though the model has been

criticised to simplify the complex context of education von Oetting (2018, p.55-115) acknowledges the positive aspect of using it as an overview of the education situation. In this section the didactic triangle will be used to describe teachers' perspective of the education situation. Lindström & Pennlert (2013, p.10) has developed an extended version of the didactic triangle as seen below (image 1). It includes the relationship between the pupils and the didactic competence of the teacher, in contrast to the original model.

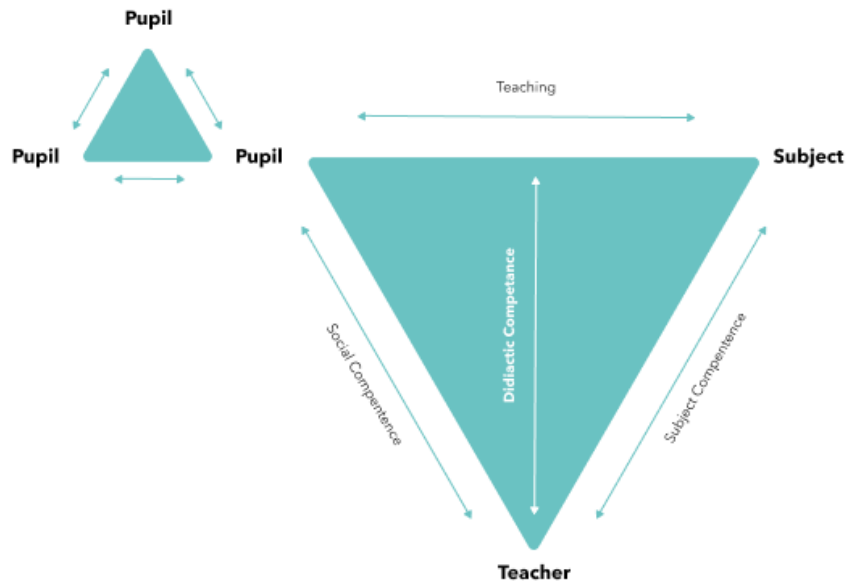


Image 1: Illustration of the didactic triangle with explanations

According to Lindström & Pennlert (2013, p.10-12) the relationship between the pupil and the subject (learner-subject) is to some extent decided by the teacher. The content is most often decided by the teacher, but the way the pupil understands the subject varies among pupils. It is therefore of interest to know the pupils' different prerequisites and what questions they may have regarding the subject. To make the most of the education the teacher needs to have didactic competence, which can be summarised as teaching skills (Lindström & Pennlert, 2013 p.10-12). Further, the teacher should guide the pupil through their education, meaning that they need knowledge about the subject they teach and how the pupils learn. The social aspect of education is described in the relationship between the teacher and the pupils (teacher-learner) and between the pupils themselves (learner-learner) (Lindström & Pennlert, 2013 p.10-12). The teacher should not only aim to have a good relationship with each pupil, they should also foster good relationships between the pupils. As explained by Hamutoglu et al. (2019), these interactions are not limited to physical learning but also exist in online learning where they are called; learner-learner, learner- instructor and learner - content. Moreover, they argue that cognitive, social and teaching presence are important to take into account when working with these matters.

### **2.1.3 Pupils' Perspective**

Von Oetting (2018, p.55-115) describes the differences between the education situation and learning in the "real world" and acknowledges the importance of repetition and failure. When a person receives praise or confirmation dopamine is released in the brain (Bähr, 2015, p.65-75). Therefore, it is important to encourage pupils who are making an effort so that they get positive feedback on not only the results but also the effort they put in. When the pupils are rewarded for their effort, the pupils can feel more comfortable to take risks and thus reach higher results.

Pupils engage with different senses when they learn and the most dominant ones are the visual and auditativ (Kajetski and Salminen, 2013, p. 13). There is a connection between what sense the pupils engage most and what learning strategies they use. The pupils who learn best auditatively will for example use rhythm to learn whereas children who learn visually may see numbers as groups. Olsson and Forsbäck (2008, s. 20-23) suggest that one visual strategy is to let the pupils reflect about the assignment by drawing it. Another important aspect when it comes to learning is the motivation of the pupil. The pupil who is eager to learn will more easily adopt theoretical skills to everyday situations (Illeris, 2015, p.103-125). Which in turn will affect their memory capacity.

When educating children it is important to not only focus on what they should learn, but also their prerequisites. Even if the pupils are a part of the same education they will learn different things based on their previous knowledge (Illeris, 2015, p.125-155). To encourage learning it is important that the challenges that the pupils encounter are at a well balanced level (Illeris, 2015, p.125-155). If it is too difficult the pupil will give up and if they are too easy the pupil will learn too little.

### **2.1.4 Summary**

In summary, the main aspects of learning is that it is; situated, social, distributed, mediated, relies heavily on language, and the participation in communities of practice. Furthermore, the teacher should foster a good relationship between pupils. They need knowledge about the pupils prerequisites and how they learn since it is important that the challenges the pupils encounter are of a suitable level. The learning strategies used by the pupils vary and to meet these, the learning material can include for example rhythm or drawing. Further, it is stated that failure, repetition, motivation and feedback on effort are important factors when learning.

## **2.2 Mathematics**

Mathematics is, according to Olanrewaju (2019), a subject of significant importance for the students development as it teaches problem solving through observation, reflection and reasoning. Further, it teaches students how to communicate ideas and is key in, among other topics, science and technology. Olsson and Forsbäck (2008, s.10-11) explain the importance of mathematics in everyday life as adults use it for example when buying food, cooking dinner or in their work life. These aspects of mathematics are also an aim that is stated in the Swedish curriculum (Skolverket, 2020a, author's translation): "The education in the subject of mathematics should aim for the pupils to

develop knowledge of mathematics and the skill to use mathematics in everyday life and within different subject fields." This is further supported by Rudyanto, Guhfron, & Hartono (2019) who suggest that through mathematics analytical, critical, creative, and logical thinking is developed.

### **2.2.1 Concrete and Abstract Mathematics**

Olsson and Forsbäck (2008, p.10-11) state that the mathematics encountered in everyday life is usually concrete whereas the mathematics encountered in school can be experienced as abstract and therefore pointless. Kajetski and Salminen (2013, p. 8) elaborate on this by stating that the children learn by moving from working with concrete mathematical problems to working with abstract ones. Thus, it is considered important for the learning process that both concrete and abstract problems are included in the education. Further, any visuals that support the learning should be clear and aesthetically appealing so that the pupils understand what they are supposed to learn and feel attracted to the support (Kajetski and Salminen, 2013, p. 15). This can be seen in *Matte A Mosaik*, a mathematics book for pupils in year three (Johansson, Karlsson, Olstorpe, & Skoogh, 2000), In the book, characters use coins to illustrate how much for example ten plus five is. These illustrations are mixed with rows of additions for the pupils to calculate with less or no visual support. To implement the knowledge gained in education to everyday life and practice reflection has been acknowledged as a key success factor when learning (Illeris, 2015, p.75-103). By reflecting individually or with others the knowledge can be processed and transferred to relevant practice. Olanrewaju (2019) stated that mathematics can be viewed as punishment and cause stress in pupils but that studying mathematics collaboratively improves the attitude towards the subject and leads to better results.

### **2.2.2 Learning Mathematics by Language**

Olsson and Forsbäck (2008, p. 20-23) emphasise the importance of using language as a means of learning mathematics as it helps the pupils to learn and apply the terms. They state that teachers are not able to let every individual pupil speak during a class, and that a suggested solution is to allow for discussions in pairs or groups. The notion that language is important for deeper learning is supported by Baturay and Toker (2019) who state that discussion, debate and argumentation allows for knowledge formation. Kajetski and Salminen (2013, p. 11) further emphasises this by stating that working in pairs or in small groups is essential in well-structured mathematics classes.

### **2.2.3 Summary**

To summarise, it is important that the pupils can practice both concrete and abstract mathematical problems to be able to learn how to implement their knowledge in everyday situations. Further, reflections individually or with others have shown to ease this transition. To enable all pupils to use the language as a tool to learn mathematics, discussion can be conducted in groups or pairs. Beyond discussions, debate and argumentation are also important methods to create deeper learning. Further, by working collaboratively the pupils attitude towards mathematics and their results are improved.

## 2.3 Collaborative Learning

There is no common definition of collaborative learning and it varies among scientific areas. The most generic definition described by Dillenbourg (1999, p.1-20) is "a situation in which two or more people learn or attempt to learn something together." However, Dillenbourg describes this definition as unsatisfying since it can be interpreted in many ways.

Kumi-Yeboah (2018) views collaborative learning as a pedagogical approach and states that it is beneficial as it promotes deeper learning and that when incorporated in online learning it can be more efficient than face-to-face classes. Further, it can be defined as a pedagogical process which allows students to exchange information and perspective to gain knowledge or solve problems (Vreeman, 2000, in Kumi-Yeboah, 2018). Kock (2018) defines electronic collaboration to be "collaboration using electronic technologies among different individuals to accomplish a common task."

Stahl Koschmann & Suthers (2014, in Peterson, Beymer and Putman, 2018) suggest that when a shared group meaning has been created and agreed upon within a group of students working together it is defined as collaborative learning. When the work is more structured and encourages interdependence between students it is instead defined as cooperative learning (Peterson et aln, 2018). They further state effective communication, coordinated efforts, and group members holding similar beliefs and values to be factors that indicate that the interactions between the students are of positive interdependence. Indications of negative social interdependence are negative attitudes towards each other and struggling to coordinate efforts (Peterson et al, 2018).

Baturay and Toker (2019) highlight collaborative learning as a way to create deeper learning as the pupils are involved in discussions and are interacting with each other. Further, they state that one of the key success factors in collaborative learning is establishing trust within the group as positive feelings within the group can increase motivation whereas negative emotions may have the opposite effect. Hensvold (2006, p101) describes the winners of collaborative learning as the under-, middle-, and overachievers. The overachievers can learn by explaining the assignments and solutions to others whereas the underachievers can learn new strategies by observing others. Howe and Zachariou (2017) however, stresses that there is no guarantee for individual benefits in collaborative work.

In this thesis, the definition of collaboration which is used is derived, adopted, and adapted from the definitions of Dillenbourg (1999, p.1-20), Kumi-Yeboah (2018), and Stahl Koschmann & Suthers (2014, in Peterson et al, 2018). It is as follows; A situation in which two or more pupils with shared purpose can exchange information and perspective to learn or attempt to learn something together. This definition was constructed as the previous definitions were considered either too wide or too narrow for the scope of the thesis.

### **2.3.1 Individual and Group Performance**

By comparing individual and collaborative learning it is shown the same learning mechanism can be triggered by individual learning, but some of the activities that trigger these mechanisms occur more often in collaborative learning (Dillenbourg, 1999, p.1-20). Examples of these are explanation and disagreement which in turn can lead to learning. The positive outcome of difference of opinion within collaborative learning, in middle and late childhood, is also supported by Howe & Zachariou (2017) that state that it results in both growth and individual cognition.

When evaluating the success of collaborative learning one can either focus on the individual assignment performance measures or the group performance measures (Dillenbourg, 1999, p.1-20). Howe and Zachariou (2017) states that there is no relation between individual growth and the results of collaborative work. Howe & Zachariou (2017) shows that groups that did not agree during the assignment were as effective as the groups that did. Therefore, the focus should not be on the result of the assignment but rather the factors that concern explanation. Dillenbourg (1991, p.1-20) also discusses the effect of collaborative learning as a way for the individuals in a group to develop their skills to actually collaborate, which later can be used in future projects and professions if you are a student. By only focusing on the individual cognition of the student the aspect of being able to collaborate with others is lost.

### **2.3.2 Design of Assignments**

Group assignment can be divided into five categories; additive, compensatory, disjunctive, complementary and conjunctive (Hammar Chiriak, 2008). The result of an additive assignment is the sum of the members' individual contribution where all contributions are added with equal weight. Hammar Chiriak (2008) suggests that rope pulling is an example of an additive assignment. In a compensatory assignment the group's opinions are averaged and that average is then the result of the assignment, for example, this is how a jury could work. To solve a disjunctive assignment it only requires one person to understand the assignment or one group member may take the charge to finish the assignment faster. This can cause some group members to be excluded. This can be perceived by the excluded pupils as a confirmation of being inadequate (Granström & Einarsson, 1995). Bähr (2015, p. 65-75) further elaborates on this by stating that some pupils may even have strategies in place to avoid being assessed at all. For example, if a pupil is worried about failing an assignment they can avoid assessment by not handing it in or not coming to school. The fourth type of assignment, complementary, is divided into sub-assignments where members take individual responsibility for their part of the assignment and the individual parts are added together to create the result (Hammar Chiriak, 2008). According to Granström & Einarsson (1995) the result of the assignment is not dependent on the collaboration among the students which is further supported by Hammar Chiriak (2008) who states that no interactions takes place between the individual contributions. The last type of assignment, conjunctive, requires all members to understand and succeed for the group to succeed (Hammar Chiriak, 2008).

To minimize the risk that group work in fact are individual work that has been merged to a joint result Lindström & Pennlert (2013, p.59-69) present guidelines based on Arfwedson studies *Arbete i lag eller grupp* from 1992. The guidelines can be summarized as; the

members of the group should know the purpose of the assignment, be individually prepared beforehand and know how the result should be presented and evaluated. The assignment should be designed so that it requires collaborative work and enables discussions, problem solving and exchange of knowledge and opinions. Further, it should enable comparison between the members' opinions and their work load and make all the members take responsibility. Finally, the group work should be organised so that everybody's contribution is used.

### **2.3.3 Problem Solving**

In the Swedish curriculum of mathematics (Skolverket, 2020a) it is stated that the pupils should develop their ability to communicate about mathematics in everyday and mathematical context. Further, they should be able to argue logical and recount for problem statements, calculations and conclusions. To enhance the quality of the result and learning process during collaborative work the teacher should follow up throughout (Lindström & Pennlert, 2013, p.59-69).

### **2.3.4 Social Factors within Collaboration**

Hamutoglu, Gemikonakli, and Gezgin (2019) argue that when working collaboratively a sense of community within the class can be built as the group works towards a mutual goal. Further, they state that working together in a collaborative manner is a natural way of learning that can have a positive impact on the classroom. Corresponding to this, one of the guidelines in the Swedish curriculum is that everyone working at school should foster the pupils ability to take responsibility over the social environment in the classrooms (Skolverket, 2019). Further they should contribute to develop the pupils' feeling of community and responsibility of others.

### **2.3.5 Summary**

The definition of collaborative learning that will be referred to in this thesis is A situation in which two or more pupils with shared purpose can exchange information and perspective to learn or attempt to learn something together. The positive outcomes of collaborative learning can be summarised as follows; builds a sense of community within the class, pupils with different prerequisites learn together, pupils learn how to collaborate, higher chance of individual growth. To stimulate successful collaborative learning the following aspects are of interest; trust within the group, explanation, argumentation, mutual regulation, observation. To strive towards inclusion of all pupils in collaborations the nature of the assignments could be considered, since they can be designed to require participation of all.

## **2.4 Designing for Children**

Including children in user studies can have two purposes; firstly, children have a different perception of reality than adults which therefore makes them hard to predict and secondly, to give them the opportunity to be included in decisions regarding their environment (Read & MacFarlane, 2006). When involving children by conducting interviews the questions should be phrased open-endedly to increase the response

reliability. An example of such a question is "Can you tell me about a day in school?" Druin (1999) states that technology is an important part of children's lives both for educational purposes and out of school activities. Further, she explains that children have difficulties expressing what needs they want a technology to meet but that asking questions in a context such as a home environment or school makes it easier for them. To additionally aid the children in expressing their thoughts and opinions low-fidelity prototypes can be utilised.

Read & MacFarlane (2006) found that an important factor in determining whether or not children use an interactive product is how fun they find it and that this factor can be used as an evaluator when comparing different concepts.

### **2.4.1 Summary**

To increase the reliability of the children's answers and to make answering simple, the questions should be open-ended and posed in the school environment. Low-fidelity prototypes can be utilized as a facilitator to allow the pupils to express themselves and what they find fun can be used as a factor to compare concepts to each other.

## **2.5 Digitalisation in Classroom**

Globally, it has become increasingly important to integrate digital technologies in the educational programs and both learning about the digital tools as well as through them is key in a formal education (Harju, Koskinen, and Pehkonen, 2019). In 2018 the government of Sweden decided on a national strategy to foster the digitalisation in the education system (Skolverket, 2020b). The goal is for the pupils to achieve a high digital competence and the education system should foster the development of knowledge and equal value. Furthermore, the pupils should be given the opportunity to develop their digital skills and the opportunity to use digital tools to foster their knowledge (Skolverket, 2020a). One of the goals includes that pupils can use digital tools for problem solving and communication. Digital skills are considered to be part of what UNESCO lists as transversal skills (Harju, Koskinen and Pehkonen, 2019). The same authors state that elements of the learning culture is a key factor when integrating digital tools in a learning environment.

The guidelines in the Swedish curriculum states that the school should provide a critical view of digital technique as well as its risks and possibilities (Skolverket, 2020b). Harju, Koskinen and Pehkonen (2019) found that digitised teaching of mathematics has both positive and negative effects on the students with regards to affection, attitude and motivation. Introducing digital devices has resulted in a significant non-educational usage of said devices, however, the introduction has also been reported to increase motivation. Further, allowing the users to feel in control over the device can have a positive effect on helping students to view the technology as a tool rather than a source of entertainment.

### **2.5.1 Summary**

To summarise, it can be stated that digitalisation is becoming an increasingly integrated and important part of education. Swedish pupils should develop digital skills that can be used for problem solving and communication. Use of digital devices can increase motivation, however considerations regarding non-educational usage should be taken into account.

## **2.6 Swedish National Steering Documents**

Democracy is the foundation of the Swedish education system and the pupils should through the education not only be provided with knowledge of democracy, but it should also be practiced throughout the education (Skolverket, 2019). The education is regulated by the national steering documents which consist of the education act, education ordinance, curriculum and criterias for certificates (Lärarnas riksförbund [LR], 2019). These documents are mandatory to be followed by the schools and child care. The content of the documents that is considered to be the most relevant to this thesis are summarised below.

### **2.6.1 Education Act**

The Swedish parliament decides over the education act which consists of regulations regarding the educational system of Sweden (LR, 2019). In the Swedish education act (SFS 2010:800, authors' translation), chapter 10, 2§ the aim of the education in primary school is defined as follows:

“The primary school should provide the pupils with knowledge and values and develop the pupils' ability to adopt these. The education should be designed to contribute to personal development and prepare pupils for active life decisions and function as a basis for future education. The education should foster versatile contacts and social community and provide a good foundation for active participation in social life.”

### **2.6.2 Curriculum**

The curriculum of the primary school (Skolverket, 2019) consists of five categories, where the category Fundamental values is considered to be the most relevant to this thesis. The Fundamental values describe aspects such as understanding and compassion, including that for example the school should foster an understanding of others. Furthermore, the education should be adopted to the pupils individual prerequisites and strive to be a community that creates a feeling of safety (Skolverket, 2019).

### **2.6.3 Syllabus**

The syllabus of mathematics in primary school describes the aim of the subject and its central content (Skolverket, 2020a). The central content is divided into six subjects within mathematics;

1. Understanding and perception of numbers and the use of numbers
2. Algebra
3. Geometry
4. Probability and statistics
5. Relationship and change
6. Problem solving

### **2.6.4 Summary**

To summarise, the pupils in primary school should be fostered to understand and have compassion for others. The education should be adapted to prerequisites and prepare the pupils for their future life by providing them with knowledge and values. The pupils should be taught understanding and perception of numbers, algebra, geometry, probability and statistics, relationship and chance, and problem solving.

## **2.7 Activity Theory**

Kaptelinin & Nardi (2006, p 5-6) state that activity theory is an approach which aims to understand technology in the context of how it is used in human activities, taking social, emotional, cultural and creative factors into account. They continue by arguing that activity theory is a way to gain a broad perspective on a subject and organising these thoughts through a tool. The theory is applied in many fields such as psychology, work research and education. In activity theory the link between consciousness and activity is of special interest, where consciousness encompasses the ability to, among other things, pay attention, memorise, learn, reason and reflect (Kaptelinin & Nardi, 2006, p 8). These skills are stated to be crucial to the human existence as they are used and realised in everyday activities.

An activity can be described as a subject's doings directed towards an object (Kuutti, 1996) which is formed by the motive or motives of the subject (Selvefors, 2017). The motives are derived from the needs of the subject and are often unarticulated. The existence of an activity is motivated by the transformation from an object to an outcome (Kuutti, 1996). To mediate the doing there is a tool, which enables the subject to act upon the object (Bødker & Nylandsted Klokmoose, 2011). Bødker & Nylandsted Klokmoose (2011) exemplifies a tool as a hammer to help the subject drive a nail as one of the mediators when building a house. Further, they state that a functioning mediator should not draw attention to itself, but work as a tool to achieve the object.

Engeström understood activities as something collective rather than individual (Kaptelinin & Nardi, 2006, p 98). To better include the whole context Engeström developed the activity system model which includes subjects, objects, community and three different mediators; tools, division of labour and rules. To exemplify, the subject could be a pupil, object a learning goal, community the class and tool an iPad. Further, the division of

labour could be exemplified by the teacher being responsible for explaining and the pupil responsible for writing. Lastly, the rules could be that the pupils are not allowed to talk while the teacher is giving instructions. To understand the human actions it is important to understand the context they are situated in (Kuutti, 1996). The relationships between the elements are described in the triangular model seen below (image 2). This model is believed to be useful for analysing and evaluating technologies and systems (Kaptelinin & Nardi, 2006, p 99). As this thesis is concerned about how a technology can be integrated in the school system it will be utilised for both analysis and evaluation.

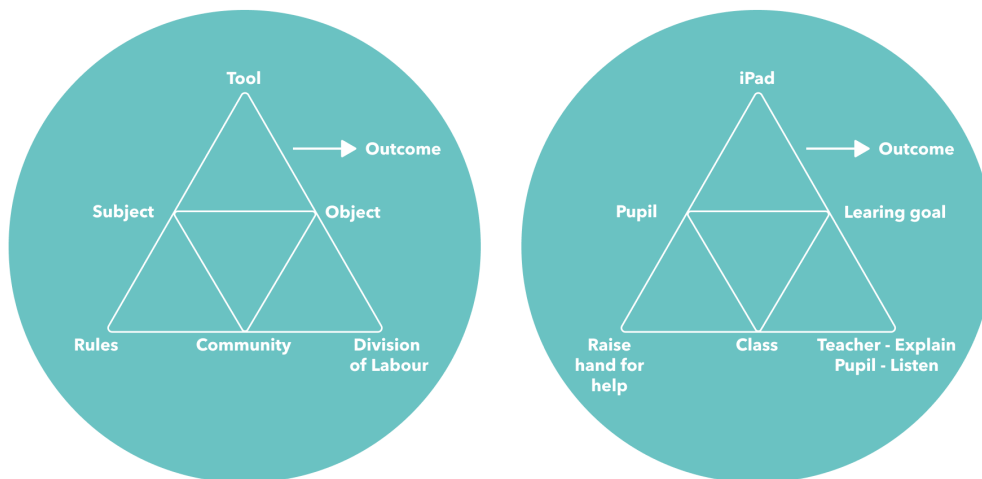


Image 2: Illustration of Engeström's activity system model with the meaning of each element in this thesis explained on the right.

### 2.7.1 Matches and Mismatches

In the model matches and mismatches can occur between the elements which Selvefors (2017) describes in her disputation. She states that a mismatch can for example occur between the subject and tool when the artefact does not allow the subject or motivates the subject to achieve the object. Further, these mismatches can be the result of the design of the product which influences the users' behaviours and their ability to reach the goal of the activity.

### 2.7.2 Internalisation of Knowledge

Activity theory is concerned with the processes of externalisation and internalisation, meaning that a process which was previously mediated by an external tool is redistributed to be internalised (Kaptelinin & Nardi, 2006, p 43- 45). An example of an action moving to the internal plane of actions is when a child learns how to perform calculations, where they initially may use their fingers as an artefact (Kaptelinin & Nardi, 2006, p 8-9). This artefact can aid them in, for example, adding or subtracting numbers. However, the child is no longer in need of the aid from the external artefact once they have learned how to perform the calculations in their head.

### 2.7.3 Hierarchical Structure

The activity theory is divided in a hierarchical structure where an activity can be divided into several actions, which in turn can be divided into operations (Bødker & Nylandsted Klokmoose, 2011). Actions are performed with the intent of fulfilling a defined goal (Kuutti, 1996) and to fulfill the goals the subject is mediated by a specific tool. The actions together contribute to the overall object and motive of the activity (Kuutti, 1996). The last step of the hierarchy consists of operations, which are the execution of an action that is unconscious to the subject (Bødker & Nylandsted Klokmoose, 2011). The difference between the steps of the hierarchy is not static, but can change over time (Kuutti, 1996). An activity can change into an action and vice versa and the same goes for the operation and action dynamics. With practice an action can be transformed into an operation and if the subject encounters a breakdown during an operation it is transformed into an action as seen in image 3 (Selvefors, 2017).

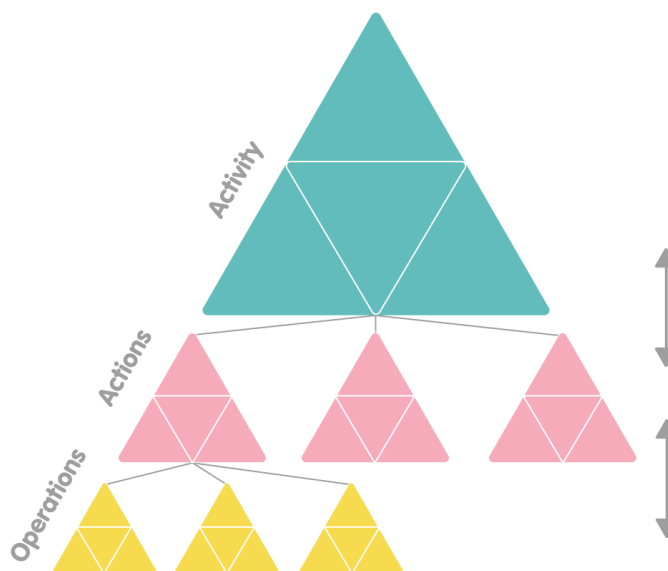


Image 3: Hierarchical structure of the activity theory

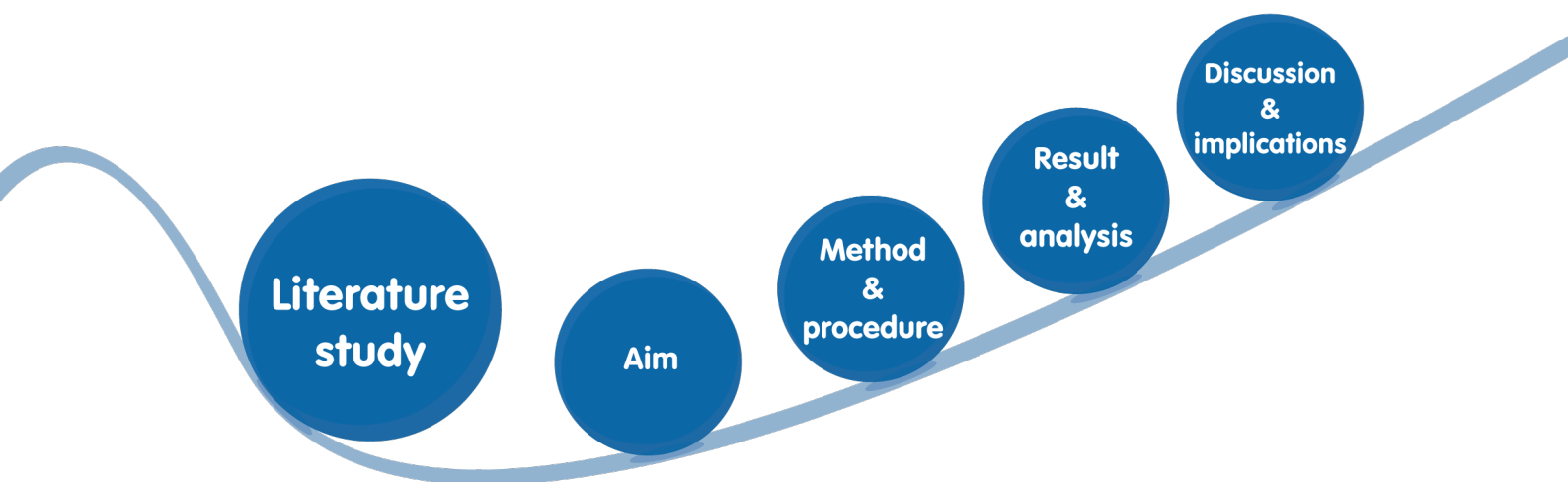
### 2.7.4 Summary

Activity theory is an approach that can be used to understand human behaviour in relation to technology. Within the theory a subject uses a tool to achieve an object because the subject has one or several motives. Within the expanded activity system model the elements community, division of labour, and rules are also taken into account. Matches and mismatches that impact whether or not the object is achieved can occur between all elements. What the subject does is divided into a hierarchy consisting of three levels, activities, actions and operations.



## 3. Literature Study

The purpose of conducting a literature study was to give the authors an introduction to the relevant topic and thus increase the quality of the user studies. This was done by searching for and reading academic papers and books on the relevant topics. The results of this study are presented in the Frame of Reference (chapter 2).



### 3.1 Aim

A literature study was conducted with the aim of collecting theoretical data on several topics that were relevant to this thesis which later could be compared to the findings from the user studies.

### 3.2 Method & Procedure

The initial phase of the project focused on gaining knowledge about the six subjects;

- Educational science
- Mathematics
- Collaborative learning
- Digital tools in the classroom environment
- Design for children
- Activity theory

The information was gathered by searching for academic papers through the service of Chalmers Library and Google Scholar, reading books on education science and researching the Swedish school law as well as primary school curriculum online.

### 3.3 Result & Analysis

The data was then summarised and presented in the frame of reference of this report. Further, the insights drawn functioned as a basis to design the phases where pupils and teachers were involved.

## **3.4 Discussion & Implications**

The results presented in the Frame of Reference (see chapter 2) provided a foundation for the following phase of the thesis, where the pupils were to be studied in their context.

### **3.4.1. Discussion**

Some of the topics presented in the frame of reference are developing quickly and the literature is therefore sensitive to time. This is especially true for electrical collaboration and digitalisation. Therefore, the authors have been careful to mainly include recently published literature on this field which has limited the amount of available literature.

A significant amount of the presented literature regards users that are older than the primary school pupils that this thesis is concerned with. The authors have interpreted the literature as applicable to children but expect that children will act in a different manner than adults. For example, a child is not believed to use the same words as an adult when discussing a problem. The same terms could also be interpreted differently if they are performed by an adult or a child. For example, a discussion between adults or children would likely differentiate in terms of depth and length.

### **3.4.2 Implications**

The literature study provided the authors with theoretical knowledge about the relevant topics which could be used as a basis for planning the user studies in the following phase. Furthermore, the summarised literature could be used to compare theory on how education and collaboration should work to how it is implemented. The theory of the Activity System Model was used to organise the insights of the user studies in context.

User studies in context

Aim

Method & procedure

User studies with children

Mind map

Observations

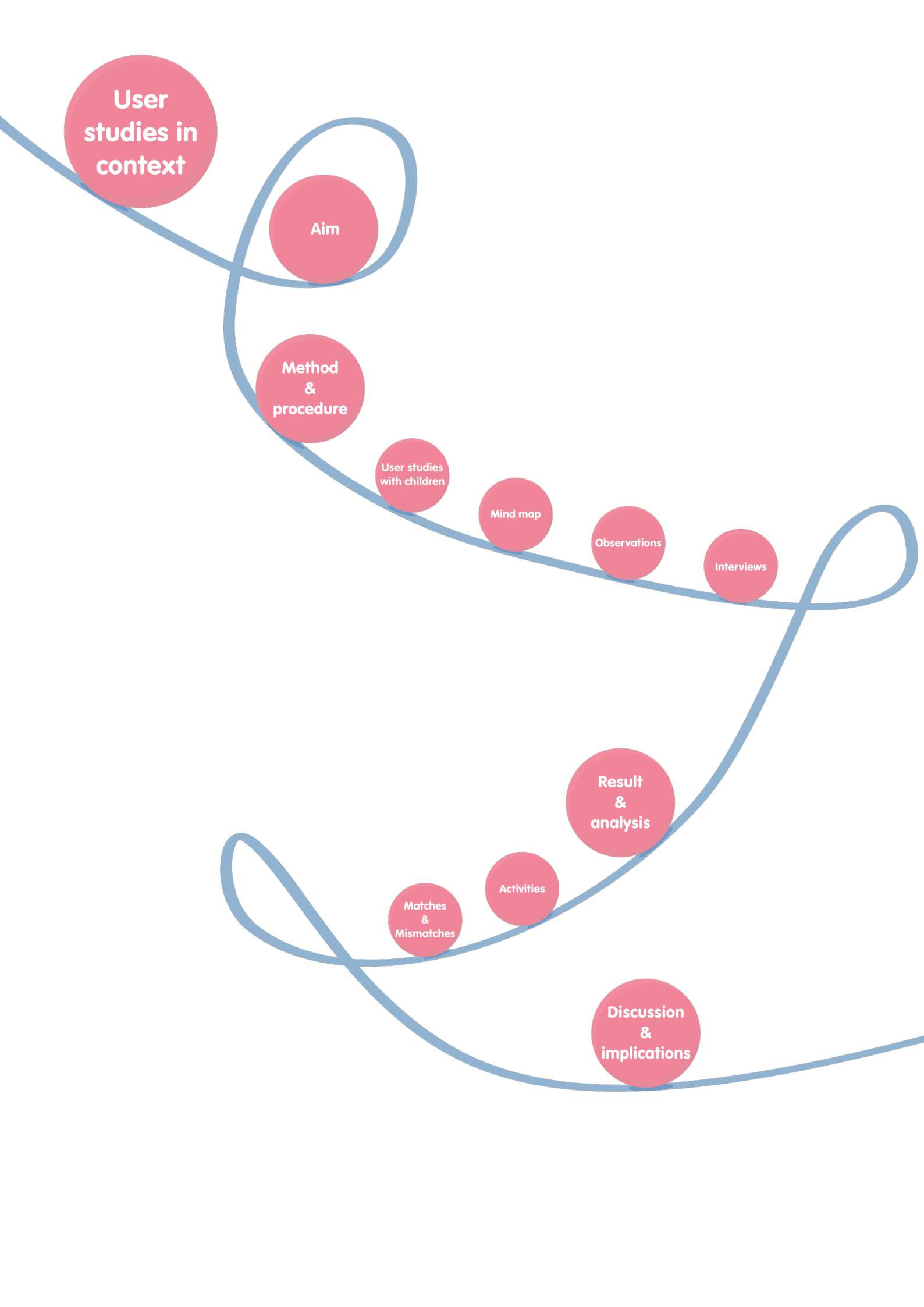
Interviews

Result & analysis

Activities

Matches & Mismatches

Discussion & implications



## 4. User Studies in Context

The purpose of conducting users studies was to explore what factors enable the pupils to learn mathematics by collaborating in the classroom context. This was done by conducting observations at three schools, interviewing six pupils, five teachers and two experts within the area of constructing mathematical assignments. The research that was summarised in the frame of reference served as a knowledge base for conducting the observations. The gathered data was analysed with the activity system model and the matches and mismatches were categorised to be addressed in the following phases. Areas that needed further investigation were described and created a foundation for the next phase.

### 4.1 Aim

The aim of this phase was to understand how the theoretical aspects found in the literature study were applied in the actual context, the classroom. Further, the aim was to investigate and identify factors that affected the pupils ability to collaborate, both related to their context and their individual differences.

### 4.2 Method & Procedure

This chapter describes the methods used during the user studies in context of this project. As the process was iterative, some methods were used several times. Due to the fact that the scheduled activities rely heavily on the children's willingness to participate, the methods including children had to be applied with flexibility so that they found participating comfortable and fun. Therefore, most methods were applied in a semi-structured manner, meaning that a structure was followed but the authors had the opportunity to add to or change the structure somewhat. Further, the user study consists of a variety of methods with the purpose of ensuring quality of the insights through triangulation, i.e. compare and combine data sets.

To gain a deeper understanding of how to conduct user studies with children a meeting was held with a researcher at Chalmers University of Technology. The researcher teaches user centered design and has experience with conducting user studies and co-design with children. The purpose of this meeting was to ensure that the methods used were adapted to the cognitive abilities of the pupils and were applied in an ethical manner.

To initiate this phase the authors made mind maps of their associations with the subject. This was followed by planning and conducting interviews and observations in three schools. Afterwards the results were analysed in an iterative manner and presented with the activity system model.

### **4.2.1. User Studies with Children**

Guidelines for how to create surveys for children have been created by Read & MacFarlane (2006). Out of the nine guidelines the following are considered to be relevant for this user study;

1. The activity should fit the children's time span.
2. Teachers can provide valuable help in determining if the children will understand the language used.
3. Drawing or providing images is preferable over asking the children to write as they can be hindered by lack of writing skill.
4. Make the session fun for example by choosing fun material or handing out certificates to participants.
5. As it can be hard to foresee how well a session is going to work beforehand it is important to have a back-up plan and to triangulate the data.
6. Finally, the trust of the children has to be earned by spending time with them and learning about their culture as the interviewer has a strong effect on the quality of the interview.

### **4.2.2 Mind Map**

To initiate the process the authors made mind maps on the topics current classroom and collaborative learning. The mindmaps are visual structures of thoughts and ideas around the topics (van Boeijen, Daalhuisen, Zijlstra and van der Schoor, 2013, p 55). and were in this case used to clarify what initial association the authors had with the subjects. The purpose of this was to make any biases explicit which helped the authors to reduce subjectiveness by increasing awareness in the user study. The mindmaps were constructed by the authors as they wrote down and explained their associations with the topics to each other. Further, it functioned as a way to emphasize for the authors what discoveries had been made by comparing the results to the initial associations. This was done through discussion about the mind maps in comparison to the results of the user studies.

### **4.2.3 Observation**

Observations in classrooms during lessons were conducted to understand how the users behave in the specific context (van Boeijen et al, 2013, p. 45) and to investigate if and how collaboration takes place in the schools today. Further, van Boeijen et al (2013, p. 45) state that observations can be utilised when the knowledge about the users and their context is limited to find aspects that are relevant to the interactions and further studies. Thus, the observations were to a certain degree also participatory observations where the authors took the role of the teacher with the purpose of better understanding how the pupils think, what they find difficult and why. Furthermore, the observation was used to understand how the actual classroom context correlated to the theory of the investigated areas; digitalisation in classroom, education science, mathematics and collaborative learning (see appendix A for structure). Thus, attempting to find resemblances and differences between theory and practice.

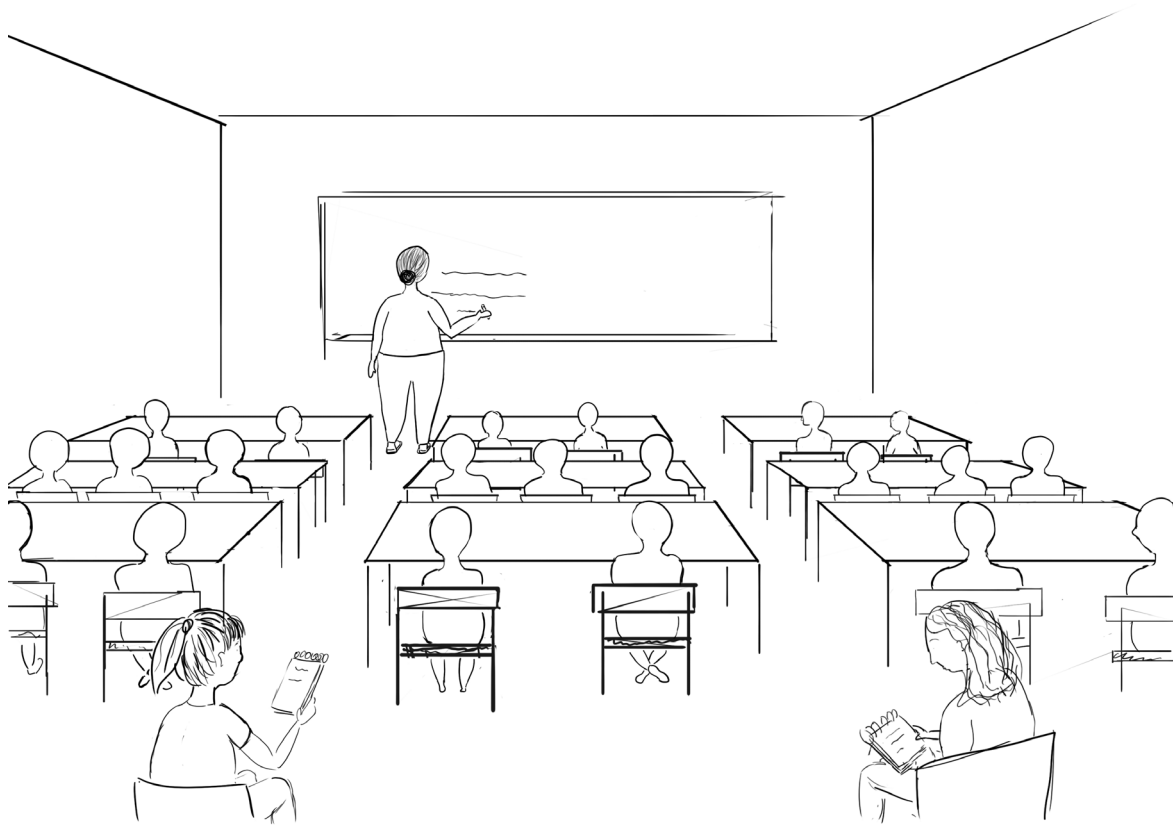


Image 4: Illustration of how observations were conducted with the authors in the back of the classroom.

The observations were semi-structured where a checklist was followed to clarify what aspects were to be investigated, for example the structure of the mathematics lessons and the attitudes of the pupils was observed. However, the checklist only functioned as a support as the authors' found it important to be free enough to take notes on unforeseen interactions that were relevant to the thesis. Thus, the method was evaluated and adjusted after each observation with the purpose of increasing the quality of the study.

During the part of the lesson where the teacher gave a lecture the observation was done by being seated at the back of the classroom, taking notes of the setup and the pupils' interactions (see image 4). The observation during the individual work and group work varied within and between the different classes. It included observation from a distance, helping the pupils, asking questions to the pupils and the teachers. Continuing, the authors were, as mentioned, sometimes able to ask the pupils spontaneous questions about their work. This proved difficult as the pupils gave very short answers to the questions and little qualitative data could be gathered. Therefore, the authors wrote eight questions that could be asked to pupils whenever an opportunity presented itself and these were complemented with spontaneous interview questions that were better adjusted to specific situations.

Observations were conducted at three schools (see image 5). To protect the personal data of the pupils and teachers the names of the schools have been changed to; Field School, Valley School and Hill School. At the first two schools observations were done continuously over a day in year one. In the third school observation was done at three mathematics classes in year two. In two of the schools the authors also observed during





One of the schools where observations were conducted.

lunch and breaks to gain trust with the pupils and observe possible collaborations in the related context. At Field School and Valley School the pupils had their own iPad whereas at Hill School the pupils had no access to iPads or other digital tools such as computers.

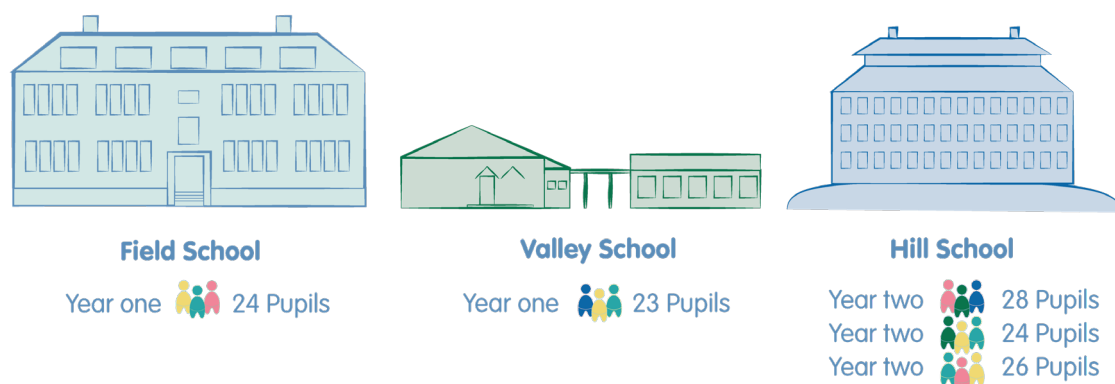


Image 5: Illustration of the visited schools and classes.

The data was collected by writing down observations and quotes from the teacher and the pupils. Photos were taken to record the environments and the tools used in the education. No pictures of the pupils were taken, instead sketches were made to visualise how pupils interacted with each other and their context.

#### 4.2.4 Interviews

Interviews were conducted with both pupils and teachers. Furthermore, two interviews were conducted with people who were considered to have relevant expertise in the area.

##### Interview with Teachers

Semi-structured interviews with teachers were conducted to understand both the theoretical and practical way mathematics is taught. The purpose of this method was to understand the teachers' perspective of the school environment regarding mathematics, digitalisation, and collaboration. Further, the interviews were conducted with the aim of gaining more insight in how the children's behaviour is over a longer period of time which adds a more long-term perspective.

Five teachers were interviewed, one from Field School, one from Valley School and three from Hill School. Due to the strict schedule of lessons the interviews varied in length and content. See appendix C for interview. The interviews were held by one of the authors while the other took notes. After the interview the authors discussed the interview and the notes together to minimize the risk of any valuable data being lost and to ensure accuracy.

##### Interview with Pupils

The aim with these interviews was to understand the pupils' attitudes towards school and mathematics. Further, their approach to collaborations and their will to ask for and give help was of interest.

Six pupils in year two participated in semi-structured interviews (see appendix B). The interviews took place during a lesson where the teacher explained that the pupils who wanted could leave the lesson to participate in interviews with the authors. The authors took Read & MacFarlane's (2006) guidelines into account when designing the setup, for example by trying to gain the pupils' trust by spending time in the classroom and keeping the interviews short (see chapter 2.4). The authors explained the purpose of the interviews to the pupils, that there were no right or wrong answers, why notes were taken during the interview and emphasised that the pupils were the experts of their experience. Further, the authors gave the pupils an opportunity to ask questions at the end of the interview.

During the interviews short notes were taken on the pupils' answers and after all interviews were conducted the authors revised the notes and discussed them together. This was done as soon as possible after the interviews to reduce the risk of losing valuable data and to ensure accuracy.

### **Interview with Experts**

The expert interviews were conducted with the goal of creating a deeper understanding of how assignments for children can be created to encourage discussion and reflection (see appendix D).

Two interviews were held, one with a university lecturer who specialises in mathematics and digitalisation and who is part of the project *Matematiska Leksaker* (Mathematical Toys, authors' translation). In the project, school classes of varying ages are invited to solve mathematical problems together by experimenting and reflecting. The second interview was held with a mathematics teacher who is part of an organisation that works to increase pupils' interest and motivation in mathematics. Furthermore, she has had a key role in developing a book with tricky mathematical questions that encourage the pupil to reflect and discuss.

During the first interview both authors were present where one asked the main part of the questions and the second took notes and could ask additional questions. The audio from the interview was recorded with permission according to GDPR. The second interview was held by one author and recorded with permission according to GDPR to enable analysis of the gathered data by both authors.

### **4.1.5 Analysis Methods**

As a significant amount of data had been gathered through the literature and user study two different methods were used to analyse it. The first one, an affinity diagram was used to cluster the data and form insights. The second one, the activity theory was used to organise and analyse the insights.

#### **Affinity Diagram**

As a first step to summarise the data from user studies an affinity diagram was constructed. This was done by reducing the data and clustering it in groups (Karlsson, 2007). The method allows for analysing detailed insights and further on move to a higher abstraction level.

The aim of this method was to retrieve an overall picture of the gathered insights and to find the connection between the different areas that were studied. Furthermore, the method allowed for a reduction of the data and a transformation from data to insights.

Insights from theory, notes from observation and quotes from pupils and teachers were written on post-it notes and then clustered into categories. This was done continuously after each observation to be able to find areas to focus on during the next observation. The clusters and the relation between them shifted after each session and the affinity analysis was seen as a continuously evolving document. Due to the extensive amount of data and perceived loss of connection to the context the authors decided to analyse the data further with the activity theory.

### **Practical Application of Activity Theory**

The purpose of using the activity theory was to structure the insights gained from the affinity diagram in a hierarchical way that could serve as a basis for creating guidelines, as seen in Selvefors (2017).

The analysis was done by defining the elements in Engeström's elaborated activity system model. A number of activities were identified and organised in triangle-diagrams. Later, actions were added to these and matches and mismatches were identified on both hierarchical levels. The operations were not analysed as no relevant insights were drawn on operational level.

## **4.3 Result & Analysis**

The insights from the literature study and the user study in context were analysed with the activity system model and are presented in this chapter. The activities will be presented in the first section, followed by the matches and mismatches. More actions can be considered to be a part of the activities, however only the essential parts that have been found to impact this thesis will be presented in this report. The results presented in this chapter are the authors' analysis of the general class, however, they vary between pupils.

Henceforth, the elements of the activity system model will be described as follows; subject - pupil or teacher, community - class or group, tool - tool will be specified and the remaining parts will be described as in the activity system model.

### **4.3.1 Activities**

The activities that the pupils and the teachers perform during a day in school are numerous and they are often intertwined with one another. The activities, actions and operations are continuously shifting as the pupils learn. During the activities the following factors were defined to be the most relevant to the result.

The lectures often had a similar structure which consisted of an introduction, individual work or group work, and a reflection in whole-class. During group work, the assignment instructions were elaborated on by the teacher by emphasising the importance of respect for one another. The division of groups was in all classes done by the teacher. The teachers took into account the social and cognitive skills of the pupils when dividing

the groups. When working in groups, the pupils were responsible for dividing the work among themselves with some guidance of rules. The pupils finished their group work at different paces and it was common that the pupils continued with individual work when finished. In the cases where the pupils did not finish their work they were able to continue at lessons dedicated to this cause.

To encourage learner-learner collaboration some teachers have a high tolerance for pupils to talk to each other whereas other teachers find it important to eliminate the noise and distractions and therefore have more strict rules. All of the visited schools do however encourage pupils to ask their fellow pupils for help.

### Solve Mathematical Problem Individually

During the individual work the pupils would sit in their assigned seats and work on a chapter in their mathematics book or app while the teacher walked around to help those who had questions. Often, the pupils were quiet and focused with the exception of when some were loud or moved around which caused distractions. It was found that a significant amount of time of the mathematics lessons was spent on individual work. This was done with the mediation of a mathematics book or a tablet with a number of different mathematics apps. The classroom also had other tools to mediate the learning such as; projector, ruler, illustrations, and stickers. The object of this activity was formulated as Learn how to calculate mathematics with the outcome to Apply it to everyday situations and further education. The activity Solve mathematical problem individually has been divided into six actions see image 6.

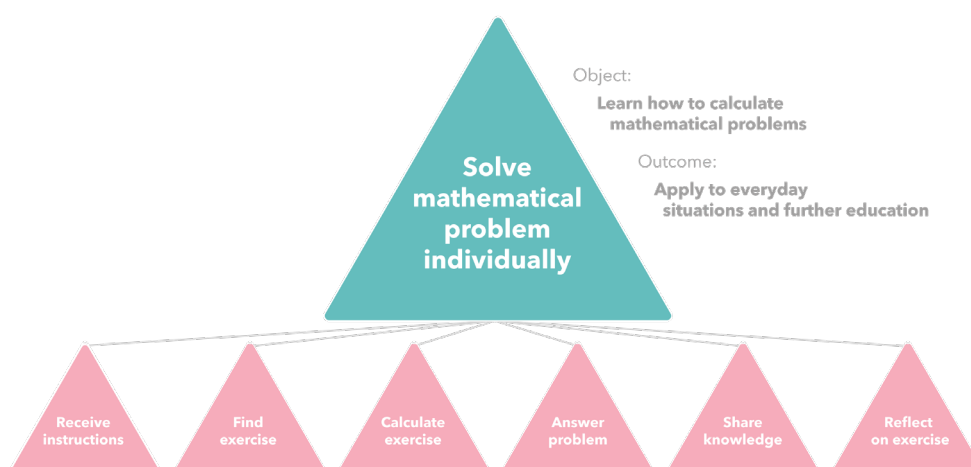


Image 6: Illustration of the activity Solve mathematical problem individually divided in its actions.

### Solve Mathematical Problem Collaboratively

The pupils were seen collaborating in different ways. For example, they played mathematical games with dice and crafting cards that they could use to practice multiplying. The pupils seemed to enjoy working together and were especially eager to play mathematical games. The object of this activity is to Learn how to calculate mathematical problems and collaborate with the outcome to Develop social and mathematical skills and knowledge. In comparison to individual work this activity demands a higher social responsibility from the pupils. This activity has been divided into six actions as seen on image 7.

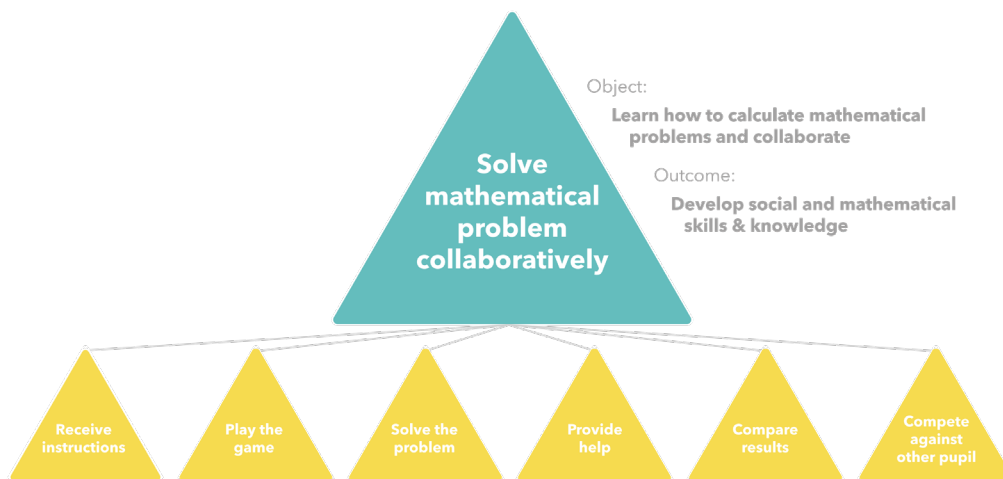


Image 7: Illustration of the activity Solve mathematical problem collaboratively divided in its actions.

### Discussing and Agreeing within Assignment

Learner-learner collaboration was also performed during lessons in other subjects than mathematics. In the activity Discussing and agreeing within assignment a lesson in civics was analysed with the mediating tool of a tablet. The pupils watched a news program in groups of two or three and then worked together on summarising what they had seen in three sentences. This was done by letting one pupil be in charge of the ipad and type on it while the group together decided on what to type. The object of the activity is described as Come to mutual decision with the outcome to Develop social skills to be able to collaborate on different topics. It can be argued that there are other more common outcomes for this activity, however, this outcome was chosen in this case as it is the most relevant for the analysis in this report. The activity is divided into two actions as seen on image 8.

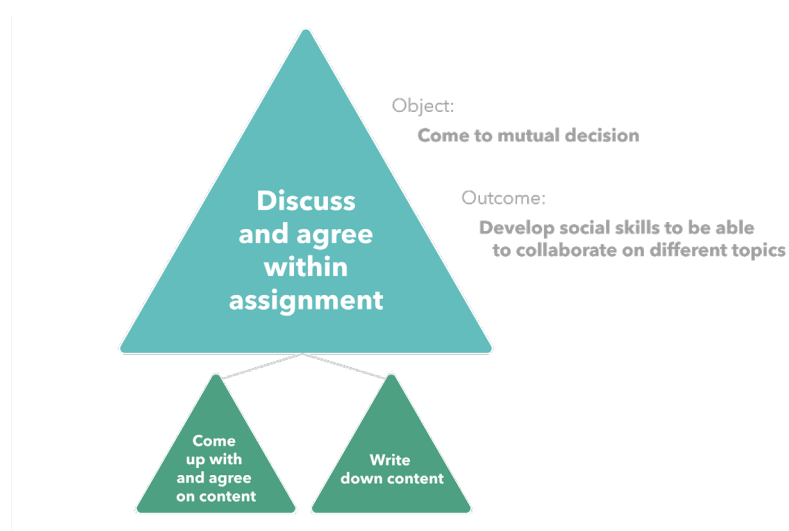


Image 8: Illustration of the activity Discuss and agree within assignment divided in its actions.

### Teach Mathematics through Collaboration

The teacher plays a significant role in the possibility for the pupils to achieve their outcome. In the observations the teachers have been seen giving instruction, offering help and mediate reflection by asking questions in whole class. The teachers provide both practical help, for example by helping solve an assignment, and emotional support by encouraging the pupils. The activity of the teacher that has been chosen for analysis is to Teach mathematics through collaboration. The object is to Develop pupils' skills, knowledge and social competency with the outcome to Prepare pupils for future education and social situations. Due to the fact that the teacher is the secondary user the activity has not been divided into actions (see image 9).

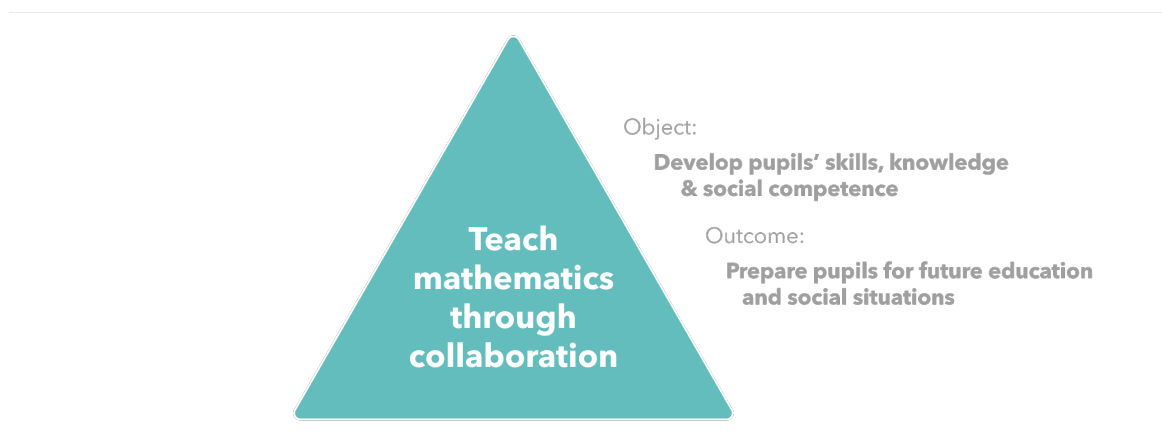


Image 9: Illustration of the activity Teach mathematics through collaboration.

#### 4.3.2 Matches and Mismatches

To further understand the activities and the actions, matches and mismatches have been identified and summarised in this chapter. The matches and mismatches have been divided into eleven categories; teacher, instructions, attitudes, educational methods & internalisation, educational & social prerequisites, focus, inclusion, communication & explanation, sharing, feedback, and reflection, which describe the problems and needs of the pupils and the teachers. These eleven categories are considered to be key aspects to take into consideration when designing for collaborative learning. For a more extensive analysis see appendix G.

#### Teacher

The apps that are available for the schools are numerous and only a few of them follow the Swedish curriculum. They can be used during mathematical lessons but it requires the teacher to put effort into finding what apps suit their pupils' knowledge. The teacher from Valley School described 90 % of the apps as inadequate.

*"If you are creative there are a lot of things you can do but you have to search for them"*  
- Teacher from Valley School

Two of the teachers described difficulties with the apps from a teacher perspective. They described it as complicated and time consuming since the interface did not give them an overview but rather forced them to click on every specific assignment to find fitting assignments to the pupils. Further they found it difficult to find and select new apps since

there were no filter options which caused them to scroll through all available apps to find the correct subject and level.

The teacher found that the apps had an advantage to the mathematics books when it came to the overview of the pupils progress. The app visualised the progress of each individual and their interactions with the app. This helped the teacher understand whether the pupils had understood how to solve the assignments or if they were guessing.

### Instructions

At two of the schools the teacher explained by drawing on the whiteboard with support from the projector which showed the assignments (see image 10). At the third school the teacher instead showed a video which was included in the mathematical book package. In comparison to the video, the teacher can explain to the pupils several times and read the room to see if pupils are struggling to understand. Further, they can ask questions, explain in different ways and draw to make sure that the pupils understand. The teachers' didactic competence and knowledge of the pupils' prerequisites as described by Linström & Pennlert (2013, p 10-12) enable the teacher to adapt the instructions to their class and it is therefore considered to be a match between the pupil and the class, where the teacher is considered a part of the class.

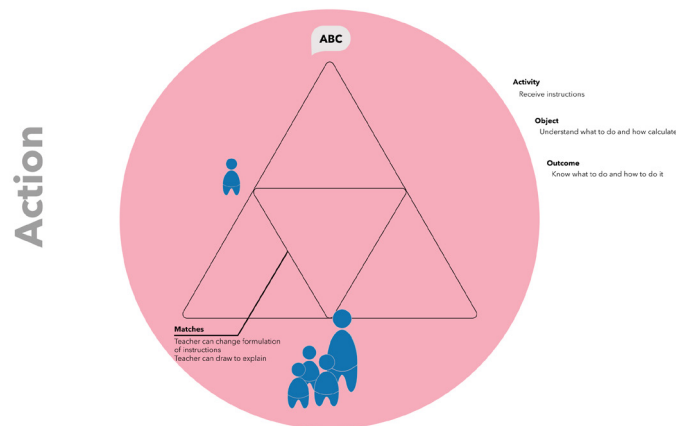


Image 10: Illustration of matches within receiving instructions.

## **Attitudes**

Overall the pupils had a positive attitude towards school, learning and mathematics. They were often eager and motivated to learn new things which, according to Illeris (2015, p.103-12), facilitate the pupils to adopt their theoretical skills to everyday life. Therefore, their motivation is considered to be a match between the pupil and the object to learn how to calculate mathematical problems. Even if discontent and dislike occurred between the pupils they most often seemed to have a good relationship and were very eager to share and help each other. Occasionally, it was clear that the pupils competed against each other but this was mostly seen during individual work.

*“So much fun because you get to learn new things”  
- Pupil from Hill School about school*

Pupils expressed joy in working together during the interviews. This was also shown in their celebration of others' and their shared progress. This was done by giving each other high fives or expressing their admiration in words. When they finished an assignment themselves they sometimes spoke out loud to share their progress with their fellow pupils. Positive feelings within the group is by Baturay & Toker (2019) described to increase motivation. The celebrations are considered to reflect this and is therefore considered to be a match between the pupil and the class.

During the observations the authors saw that the pupils enjoy different ways of individualising the tools. For example, they had edited the screensavers on their iPads and spent time editing avatars in the apps they used.

## **Educational Methods and Internalisation**

As described by Kajetski and Salminen (2013, p. 13) children use different learning strategies depending on the engagement of their senses. During a mathematics lesson in Field School the pupils were shown a mathematics video that used rhythm and songs. This is considered to stimulate the learning processes of both the pupils that engage with their auditory sense and the pupils that engage with their visual sense (Kajetski and Salminen 2013, p. 13). Hence, it is a match between the pupil and the mathematics video.

Von Oetting (2018, p.55-115) describes the importance of repetition to strengthen the knowledge. The mathematics apps provide additional possibilities for repetition which is used as a complement to the content of the mathematics book. Therefore, this possibility is considered to be a match between the mathematics apps and the object Practice skill.

Kajetski and Salminen (2013, p. 8) state the importance of allowing pupils to move from working with concrete mathematical problems to more abstractions of these problems as a way to improve learning. This is often used in the mathematics books and is considered to be a match between the mathematics books and the object Learn how to calculate mathematical problems (see image 11). Some of the apps allowed this while some only focused on abstract problems, such as practicing addition with numbers without visual support.

During mathematical lessons performed in groups, some of the pupils found alternative ways to play games. Their way of altering the rules made them practice their knowledge in a new way and internalise their knowledge. The possibility to enable their resourcefulness is considered to be a match between the pupil and the mathematics game.

It was found that language played an important role in all the lessons that were observed and this was supported by teachers who expressed that all subjects are Swedish. Therefore, the educational content should be of a level that is adjusted to the pupils skill while allowing them to practice and develop their language skills. Further, the language is important to deepen the knowledge within the different subjects (Kajetski & Salminen, 2013). Consideration should be taken to how discussions and argumentation can be implemented to allow the pupils to practice both their language but also deepen their knowledge.

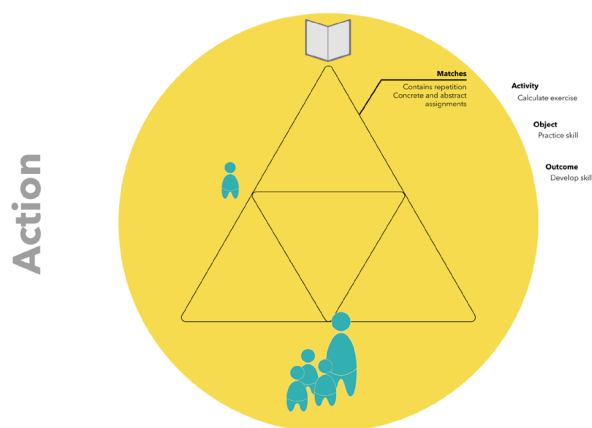


Image 11: Illustration of matches within calculate exercise.

### Educational & Social Prerequisites

During observation at the Valley School the pupils were responsible for selecting the level of difficulty in a math app. As described by Illeris (2015, p.125-155) the wrong level of difficulty can result in pupils giving up or learning too little. On the one hand, it was seen that some pupils tried a more difficult level but when it was challenging for them they selected an easier level. On the other hand, in one of the apps the teacher could beforehand select the assignments for the pupils. This could therefore be considered as a match or mismatch between the division of labour, as the pupils should not be in charge of choosing difficulty level, and object Learn how to calculate mathematical problems. The mathematics book, however, does not have the opportunity to vary the level of difficulty and is therefore considered to be a mismatch between the mathematics book and the object.

The teachers took the social aspects into account when forming the groups. They expressed that some pupils did not work together and due to them falling out or being too chatty. Negative attitudes towards each other is considered to be a factor which leads to negative social interdependence (Peterson et al, 2018). During the group work no pupils seemed to fall out, however some pupils struggled to focus on the subject and engaged in conversations unrelated to the subject.

## Focus

The pupils experience loss of focus during the day and it varies between the pupils how often it occurs. A pattern that was observed between the pupils and the schools is that the loss of focus often occurs during the shift between activities.

*"I would like to have breaks more often but it is difficult to get back to work after it"*  
- Teacher at Field School about giving the pupils breaks

This loss of focus is considered to be a mismatch between the rules and the class. To regain attention and focus the teacher made use of chants or songs and even if it sometimes required a few attempts it is considered to be a match. Further it was shown that the pupils lost their focus when the teacher was not present, which is supported by Hamutoglu et al. (2019) that acknowledges the importance of teacher presence.

*"Stop, look, listen!" - Teacher*  
*"Okay!" - Pupils*  
Example of chant used at Valley School to regain attention

During observation a mismatch between the rules and the pupil was found since some pupils disobeyed the rules by using the tablet for non educational purposes. This is supported by what the teachers said during interviews and theory, for example Harju et al. (2019) who state that the introduction of digital devices caused significant non-educational usage.

*"I can't see what they are doing on the iPad. It is easier to see when they are sitting with a math book and a pencil (...) It gets more difficult with the overview of 24 pupils."*  
- Teacher from Field School about iPad usage

Characters and avatars drew attention from education since the pupils spent time styling their avatars instead of calculating. The pupils were also eager to show their fellow pupils the characters and focused on this rather than the assignment. The way that the characters are implemented in the apps today contributes to shift the focus to the artifact itself rather than working as a mediator and is therefore considered to be a mismatch between the pupil and the app. Kajetski and Salminen (2013, p. 8) state that visual support should be aesthetically appealing to make the pupils feel attracted to them. The pupils are considered to be attracted to the characters to a high degree, however, in their current form they do not provide visual support for learning.

*"I haven't understood but you get points...then you can go to a place to buy fun clothes and hairstyle, then they are fiddling with that instead"*  
- Teacher from Field School about mathematics app

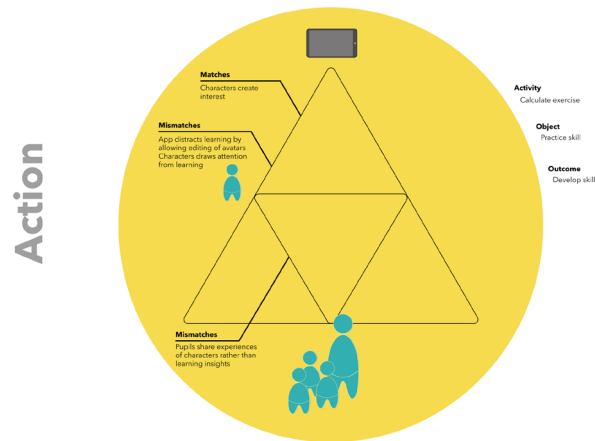


Image 12: Illustration of matches and mismatches within calculate exercise.

During the observations it became evident that when the pupils were very interested in the tool they were using they also were very focused on the assignment (see image 12). When the pupils were watching a video about mathematics they discussed the problems and suggested answers. This was also seen when the pupils tried a new app where they were very excited about the interface and discussed the interactive functions extensively. This is supported by Read & MacFarlane (2006) who state that fun is an important factor when determining if children like a concept.

The pupils were often eager to use the tablet and depending on the lesson set-up this could be a potential mismatch. In some classes the pupils who had finished their assignments in the mathematics book or group work were asked to continue by doing individual work on their tablet. In these cases the pupils who were not yet finished were drawn to the other pupils' tablets and had a hard time focusing on their own work. Further distractions that the pupils encountered when studying were from the other pupils. In some classes it was common that the pupils shouted out how far they had come or told everyone how easy they thought it was. These two types of distractions are considered to be mismatches between the tablet and the class.

*"What the f\*\*k, f\*\*k, f\*\*k, f\*\*k, f\*\*k, f\*\*k!"*  
*- Pupils from Field School*

### Inclusion

During collaborative work the involvement of members varied. During the mathematics game all the pupils needed to participate in the actual game by rolling the dice and moving the game piece, however not all pupils needed to calculate. During the lesson in civics not all members were required to participate in order for them to complete the assignment. This type of assignment is described as disjunctive by Hammar Chiriac (2008) where only one group member needs to understand and solve the assignment. This is considered to be a mismatch between the civics assignment and the object since this can exclude pupils and confirm their lack of ability (Granström & Einarsson, 1995).

In the civics class the pupils were not allowed to touch each other's iPads. They worked in groups of three with one iPad that was assigned to one pupil. One pupil was therefore in charge of writing down the results of their collaboration. In some cases where a pupil with a high level of knowledge was in charge of writing the other pupils were excluded. However, when a pupil with a low level of writing skill was in charge it contributed to more pupils being included since they needed to explain to the pupil with lower knowledge. The rules can therefore be considered as both a match and a mismatch between the rules and the object depending on the pupil's level of knowledge about the subject.

It was also found that some pupils disobeyed the rules by touching other pupils' iPads in order for them to complete the assignment faster or with less effort.

### **Communication and Explanation**

Mathematics books and apps mainly consisted of questions with a single correct answer. Both of the interviewed experts stressed that using open-ended questions are a good way to initiate discussions and argumentation between pupils. The lack of open-ended questions were therefore considered to be a mismatch between the mathematics book and mathematic app and the object.

When asked a question about an assignment most of the pupils gave the correct answer without any explanation. This helped the other pupil to move forward but did not contribute to the object of understanding how to calculate and is therefore a mismatch between class and object to Help fellow pupil understand. The questions from the other pupils were often frased to receive an answer and not an explanation on how to solve the problem. When the authors asked questions about how they calculated, most of them gave answers such as; by calculating on the fingers or in their head.

When the pupils encountered difficulties of understanding how the app worked other pupils were eager to share their knowledge. They explained step by step by interacting with the iPad in order to reach the desired result. The app also encouraged some pupils to share their knowledge with each other without being asked. This is defined as a match between class and object Understand what to do or how to calculate.

*"If you feed it it will become longer, look at mine it is quite long (...) Look how long yours has become, soon it is as long as mine!"*

*- Pupil from Valley School describing how a character in an app grows as it eats*

When the pupils were engaged in the mathematical games discussions did occur more often. Similar to individual work the pupils gave the answers without explanation, but they did more often disagree which can lead to learning (Dillenbourg, 1999, p.1-20).

Some pupils struggled with their argumentation and trusted the other pupil to have the correct answer without discussing with each other. This was seen in the mathematical game, the individual work and during collaboration. This is considered as a mismatch between the tools mathematical game, mathematical book, mathematical app and the object since the tools did not support the pupil to form arguments.

## Sharing

The teacher encourages the pupils to ask their neighbour for help which was commonly seen during the observations. Linström & Pennlert (2015, p. p.10-12) state that the relationships between the pupils are to some extent decided by the teacher, which can be seen in the example above. One of the teachers stated that it is often the pupils that are at a medium or higher level that find it easiest to ask each other for help. This could result in pupils with a lower level of knowledge not being involved in collaborative learning to the same extent as other pupils.

*"Everyone in the class are my friends and I'm not afraid of asking them for help"*

*- Pupil from Hill School*

Hensvold (2006, p.101) describes the under-, middle- and overachievers as winners in collaborative learning. It could therefore be considered important to have designated times for collaborative learning to allow all pupils to learn together. However, during the interviews all pupils said that they had no difficulties asking each other. The pupils were very direct and accepting in their feedback to each other. In the observed situations the pupils seemed to appreciate the feedback and did not take offence.

*"Mine is not good"*

*"No, erase it!"*

*Conversation about drawings at Field School*

It is common that the pupils ask each other for help when they are struggling to understand. Most of the pupils are positive towards sharing their knowledge. However, some pupils appeared reluctant to share their results which was shown by them folding their book away from the pupil beside them and by telling them to stop looking. This was not seen during usage of iPads which could be due to several reasons. For example, some of the apps do not have the same answers or provide an overview of how far the pupils have progressed. The willingness to share is therefore both a match and a mismatch between the pupil and the class.

The pupils often show pride in their knowledge and even more in their progress. It is common that the pupil tells, not only their neighbours but, many members of their class how far they have come.

*"I finished a long time ago"*

*"So did I"*

*- Pupils at Valley School*

## Feedback

The apps observed during the user studies all gave direct feedback to the pupils if their answers were correct or incorrect which is a match between the tool and the object (see image 13). However, it did not mediate the pupil to understand why their answer was incorrect, and it is therefore a mismatch between the app and object. In one app the pupils were not given the opportunity to recalculate the same assignment and were therefore not given the chance to understand what went wrong. The current feedback did not reflect the importance of positive feedback on effort rather than result which Bähr (2005, p.65-75) acknowledged as an important factor to motivate pupils. The mathematics book seldom gave the pupils feedback on their answers or effort, instead the pupils had to wait for the teacher to correct the mistakes.

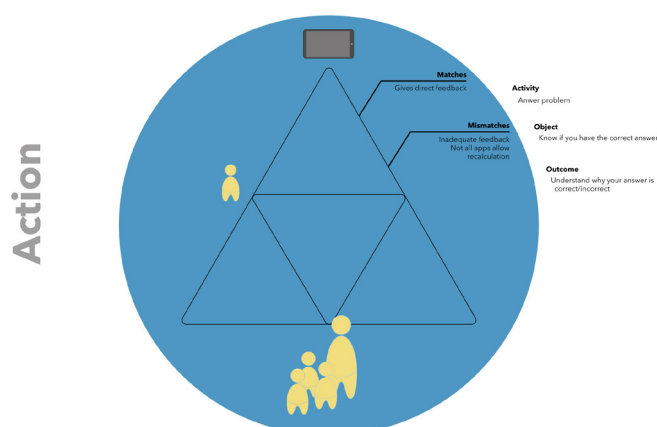


Image 13: Illustration of matches and mismatches within answer problem.

## Reflection

At the first two observations the mathematics apps provided the pupils with multiple options. It was found that some of the pupils guessed the answers instead of actually calculating. By providing the pupils with multiple options the division of labour is placed on the app instead of the pupil. This could contribute to decreased learning and is therefore a mismatch between the division of labour and the object Practice skill. In the mathematics book some assignments had options but the pupils were not given direct feedback or the option to try again and the risk of guessing without reflecting is therefore considered to be reduced.

Illeris (2015, p.75-103) stated that to implement knowledge to everyday life it is important to reflect on the knowledge either individually or with others. Support for reflection in the current apps has not been seen during the observations. Some reflective assignments have been done in whole-class at the end of the lessons, but due to the size of the class all pupils could not contribute to the discussion. This problem is also discussed by Olsson & Forsbäck (2008, p.20-23) who suggest discussions in pairs or groups to allow all pupils to participate.

Von Oetting (2018, p.55-155) acknowledges the importance of failure as a part of learning and during the observations some teachers talked to the pupils about failure and why it should not be seen as shameful. The apps or the mathematics book does not

reflect this by showing that failure is necessary for evolving and is therefore a mismatch between the mathematics books, mathematics apps and the object.

In the mathematics book the pupils have the opportunity to draw, both when calculating and when presenting their result. As suggested by Olsson and Forsbäck (2008, s. 20-23) drawing can enable the pupils to reflect about the assignment and it is therefore, considered to be a match between the mathematics book and the pupil. The apps do not enable the pupils to draw and is therefore a mismatch.

When the pupils worked with apps or assignments in the mathematics book that had clear progress or even competitive elements they seemed to be more concerned with being the fastest to progress rather than focusing on understanding. For example, when calculating in the mathematics book some pupils seemed more concerned with how many assignments they had finished rather than understanding the content. In one case the pupils competed against each other in an app where they were supposed to solve problems by choosing the correct answer the fastest. This gave the pupils little to no time to reflect on the right answer and they admitted to guessing the answers.

## **4.4 Discussion & Implications**

The process and analysis of the user studies are discussed below. The main findings are summarised under implications.

### **4.4.3 Discussion**

The classes observed consisted of 23-28 pupils. The amount of pupils made it difficult to observe all the pupils simultaneously. The focus of the authors could have been affected by the pupils who talked the most, were closely situated to the authors or in other ways drew attention. To minimize this risk the authors were in charge of observing different parts of the classroom. It is not considered to have affected the mismatches that were found, since they were evidently experienced by some of the pupils. However, the shy and quiet pupils might have faced other mismatches that were not observed during the user studies.

The activities and actions performed by the pupils were interpreted and analysed by the authors. Thus, the outcome and the goal of the activities and actions might not correspond correctly to what the pupils themselves think. This became evident when some of the pupils were unaware that they were practicing mathematics while playing a game.

### **4.4.4 Implications**

The user studies resulted in insights that were divided into twelve categories. The following matches and mismatches were found under each category.

#### **Teacher**

- Requires effort to find fitting apps with regards to both subject and level.
- Current interface of the apps obstructed the teacher to assign assignments to pupils

**Lesson time**

- No relevant insights were found within this category.

**Instructions**

- Teachers were able to instruct in more ways than the tool by changing formulation, making sure everyone understood, and by writing and drawing.

**Attitude**

- Pupils were positive and curious to learn.
- Pupils enjoyed sharing and helping each other.
- Pupils individualised their tools by changing background of iPad and styling avatars.

**Educational methods and Internalisation**

- Rhythm and songs were used to promote learning.
- Repetition was practiced in both mathematics books and apps.
- The mathematics book allowed pupils to practice both abstract and concrete problems whereas apps more often focused on abstract problem solving.
- Mathematical games made use of the pupils' resourcefulness by allowing them to change the rules.
- Language is an important factor in all educational subjects.

**Education & social prerequisites**

- Some apps allowed the pupils to select difficulty level which led to decreased motivation.
- Teacher divided groups based on social factors to reduce risk of pupils falling out or chatting too much.

**Focus**

- Focus was lost during shift between activities.
- Lack of teacher presence led to loss of focus.
- To regain focus rhythm and songs were used effectively.
- Pupils broke rules by non-educational use of tools/tablets.
- Pupils spent time styling avatars instead of calculating.
- Characters created interest with the pupils but did not provide visual support.
- Pupils were distracted by other pupils' iPad and noise from other pupils.

**Inclusion**

- The nature of the assignments were often disjunctive which could lead to exclusion of pupils.
- The rules led to inclusion or exclusion depending on pupils' prerequisites.

**Communication & explanation**

- The apps and mathematics book lacked open-ended questions.
- Pupils provided other pupils with answers but seldom explanations.
- Pupil explained how apps worked step by step.
- Discussions were more frequent during games.

**Sharing**

- Pupils were open to help each other.
- Pupils were willing to share insights with each other.
- Pupil often told others about their progress.

**Feedback**

- The apps provide the pupils with direct feedback.
- The feedback in the apps was inadequate and did not help the pupils understand.
- The mathematics books nor apps provided the pupils with feedback on effort.

## Reflection

- The multiple choice questions within the apps lead the pupils to guess.
- The tools did not aid the pupils to reflect.
- The tools did not guide the pupils to reflect about failure.
- The apps did not provide the pupils with the opportunity to draw to reflect.
- Multiple options in combination with time pressure led the pupils to guess to a high degree.

It was shown that the pupils struggled with forming argumentations and that the discussions often were short. To evaluate if this was due to the design of the tools or the skills of the pupils in their age group the authors strived to test this in the following phase. Further, how pupils come to agreement was of interest to investigate in more detail.

During the collaborative work most of the assignments observed were of a closed disjunctive nature, with a correct answer only demanding one pupil to understand. The interviewed experts explained the importance of allowing all the pupils to participate from the start and that open assignments can enable discussion. Therefore, it was of interest to test if additive assignments could function as a tool to enable all pupils to feel included and if open assignments could encourage discussion.

The importance of failure for learning was explained by the teachers but not reflected in the tools used by the pupils during collaboration. If and how this could be implemented in collaborative learning, therefore, needed further investigation.

The group size has varied, but no conclusions could be made regarding what size would fit collaborative learning of mathematics through a digital interface. Hence, further insights were needed.

Pupils showed their interest in characters in the apps, but the user study did not give answers to the factors behind their interest. To create a concept that the pupils find interesting it was considered important to explore what visual expression and what types of storylines pupils prefer.

Focus during next phase was therefore as follows:

- To what extent pupils can argument and discuss
- How pupils come to agreement
- If additive assignments could function as a tool to include all pupils from the start
- If open assignments could function as a tool to encourage discussions
- How the importance of failure can be implemented in collaborative learning
- Preferable group size when collaborating with mathematical assignment through a digital interface
- What type of visual expression interest the pupils



**Participatory session with pupils**

**Aim**

**Method & procedure**

**Ideation**

**Low fidelity prototyping**

**Participatory session**

**Solve problem collaboratively**

**Result & analysis**

**Esthetical**

**Discussion & implications**

# 5. Participatory Sessions with Pupils

In this phase, participatory sessions with classes in three schools were conducted with the purpose of enabling pupils to take part in designing the concept. Continuing, the phase builds on knowledge from the previous phase of how the children behave in the classroom, how to behave to gain their focus, and relevant matches and mismatches, such as pupils enjoy sharing and helping each other. During the sessions, the pupils created characters and landscapes that could be included in a digital interface. The gathered insights were analysed with the activity system model to be easily compared with results from previous results. The pupils' drawings and quotes about them were analysed in categories to understand what interests the pupils.

## 5.1 Aim

This phase had two aims; gather inspiration from the pupils regarding esthetical aspects and to evaluate initial hypotheses on collaborative learning.

## 5.2 Method & Procedure

This chapter describes the methods used in this phase of the project. The participatory sessions were constructed in the form of workshops with the pupils. The pupils were asked to create characters, landscapes and awards which later could be analysed to understand their esthetical preferences. Further, the workshop was designed to gain insights about the pupils ability to discuss, form arguments, and if additive and open assignments could contribute to inclusion and discussions. The workshops had varying group sizes in order to evaluate the preferred group size.

The session was planned by first ideating on its content and then prototyping the material for it. The authors role played with the material prior to the session and then conducted the session in three classes. The esthetical and educational results were analysed separately.

### 5.2.1 Ideation

With the purpose of creating a wide range of ideas the authors worked with brainwriting and brain drawing where ideas for how the session could be constructed were created in a positive and encouraging environment (van Boeijen et al, 2013, p. 119). During the ideation focus was on creating something that was fun for the pupils to participate in, that gave qualitative data and that had a coherent storyline. The authors came up with ideas separately and discussed them together afterwards. The most interesting ideas were combined into a complete participatory session.

### 5.2.2 Low Fidelity Prototyping

In order to evaluate and fine-tune the participatory session ideas low fidelity prototypes were made where the size of the material for the session could be tested. For example, the authors wanted the characters to stand up so that the

pupils could easily overview all of them. Therefore, explorations with cardboard support for the characters and different ways to fold the paper were conducted.

### 5.2.3 Role Playing

As the authors were unable to pilot test the material before the participatory session roleplaying was used to simulate how the interactions could be. Van Boeijen et al (2013, p. 157) state that role playing can be a good method throughout the design process, for example when evaluating the concept. In this case, it was mainly used to ensure that the instructions were clear enough and that the story which unfolded throughout the session was easy to follow and created interest.

### 5.2.4 Participatory Session with Pupils

A participatory session was conducted with three classes in two different schools. The purpose of the sessions was to see what underlying needs the pupils have, what visual expressions appeal to them and to evaluate how they collaborate and reflect. Throughout the sessions, a story in four parts was told to keep the pupils interested and to spark their imagination. In the sessions, the pupils would work in groups of two, three or four according to the schedule illustrated in image 14.

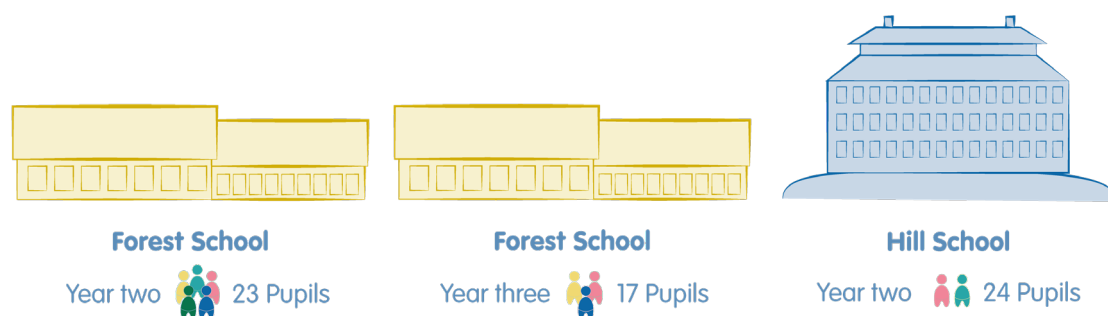


Image 14: Illustration of the visited schools. The illustrations of children indicate the largest group size.

During the session the authors took turns giving instructions and taking notes on what they pupils did or said. Prior to the participatory session, questions that could be posed to the pupils during the session were prepared and combined with spontaneous questions. All of the pupils' creations were photographed at the end of the session.

### 5.2.5 Data Analysis

After the session the notes were compared and summarised in a document. The results that were related to collaboration were analysed and presented with the activity system model. The results that were related to the esthetical appearance and the storyline of the concept were analysed by gathering quantitative data on what the pupils had drawn which was supported by qualitative data consisting of what the pupils said about their drawings. Some of the pupils' drawings were difficult for the authors to interpret. In the cases where the authors haven't been able to understand what the pupils have drawn these results have been left out, since it mostly applies to smaller details in the drawings.

# PARTICIPATORY SESSION

In this session the pupils created characters, landscaped and rewards. During the session a story was read to the pupils, where they were asked to fill in the missing information. The story is summarised below.

*Four friends are going on a journey together. They were all very excited about it. But who are the friends? What do they look like and what do they bring on the journey?*

*The friends met up at a decided spot and were ready to start their journey together. But where are they going?*

*The friends have travelled for days through the landscape you created. They are at the end of their journey and have found what they are looking for. What did they find?*



## 1. Introduction

The authors presented themselves and explained why they were doing the session and how it would work.

The aim was to:

- explain the purpose to the pupils
- make the pupils feel comfortable

## 2. Creating Characters

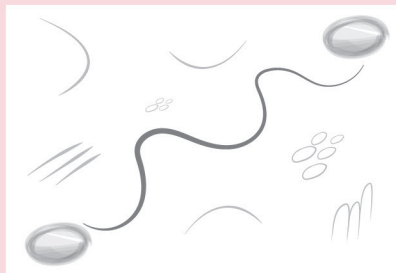


The pupils got one sheet of paper each and started by drawing a face. When they had done so, they folded the face away and passed the paper on to the next pupil who drew an upper body without seeing what the previous pupil had drawn. The sheet got passed around four times and created four characters that the pupils all had contributed to. On the final fold the pupils were asked to draw something that the character had with them.

The aim was to:

- find out what the pupils find interesting regarding characters
- evaluate starting with an additive assignment
- observe attitudes towards sharing
- observe what pupils like

## 3. Creating a Landscape

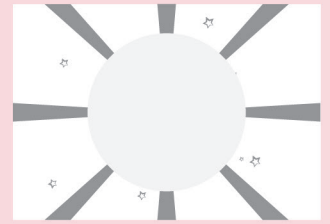


The pupils were given one A3 sheet per group with an abstract illustration on it that resembles the game plan of a board game. They were asked to create a landscape in which the characters could go on a journey by drawing and making use of geometrical shapes.

The aim was to:

- find out what the pupils find interesting regarding landscapes
- observe how they divide the work and make decisions
- explore if pupils can collaborate over one piece of paper

## 4. Creating a Reward



After having created a landscape the pupils were asked to together come up with an award that the characters would receive after having finished their journey with the criterion that they should be able to divide it equally between the characters. The pupils then drew one picture each of the award.

The aim was to:

- observe how pupils make decisions together
- explore what pupils consider to be a reward

## 5. Reflection

To sum up the participatory session and gather input from the pupils the designers asked the pupils what they thought of the session.

The aim was to:

- understand what the pupils thought of the session
- understand how the session could be further developed

## 6. Certificate



Finally, all the pupils were given a certificate as a reward for participating in the session.

The aim was to:

- thank the pupils for their participation
- further emphasize the fun of participating

## 5.3 Result & Analysis

The results of the participatory session were analysed with the activity system model where one main activity was identified.

### 5.3.1 Solve Problem Collaboratively

The main activity within the session was defined as Solve problem collaboratively as this was key for the pupils to reach the goal of the assignment (see image 15). Most of the pupils were very eager to start the assignment given to them and they seemed to enjoy participating.

*“The best way to learn is if you have fun while you learn”  
- Pupil at Forest School*

The additive nature of the first assignment (see chapter 2.3.2) of creating the characters encouraged all group members to participate from the start. Some pupils struggled with finishing the drawings within the given time, which the authors had foreseen and explained to the pupils that it could happen. This seems to have been helpful as most groups enjoyed opening their creations to see what had happened and what parts were missing. From this the conclusion was drawn that a built-in failure can be considered a match between the pupil and the provided material. The failure appeared to help the pupils have a more relaxed attitude towards mistakes.

*“But it does not have any legs”  
“No, I know I did not draw any legs”  
“Haha look, our character has no legs!”  
- Pupils at Forest School discussing how their character turned out*

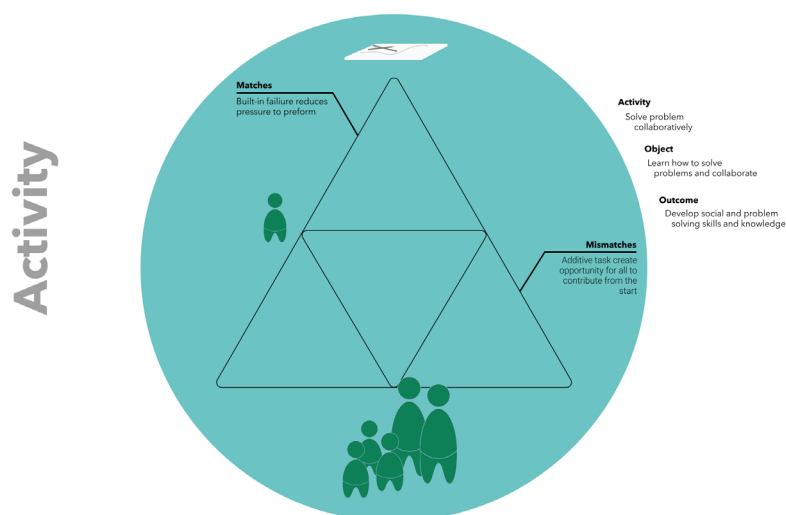


Image 15: Overview of the activity with matches and mismatches.

## Create Content

Some groups took extra care not to speak to each other during the creation of the character and even created barriers between each other so that their group partners would not see what they were making. Other groups seemed to have, judging from the results of their drawings, communicated about what they were drawing and created very coherent characters.

Most pupils were very eager to create in all parts of the session and they were quick to get started (see image 16). The pupils' teachers explained that the pupils usually aren't allowed to be as freely creative as they were during the sessions. This appeared to be greatly appreciated and was considered to be a match between the pupil and the goal of the action.

The additive nature of the assignment allowed all pupils to contribute from the start. However, it appeared to fail in creating a mutual ownership of the characters and the pupils referred to them as mine or yours.

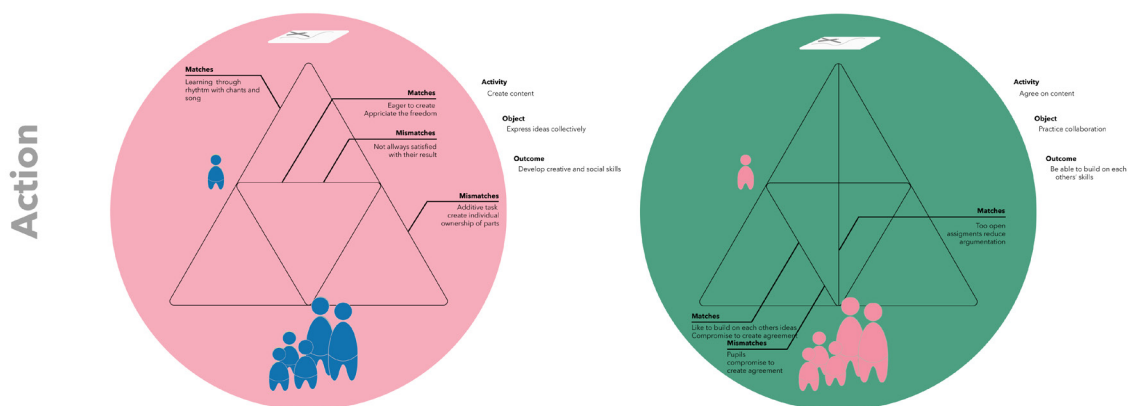


Image 16: Overview of the actions with matches and mismatches.

## Agreeing on Content

A key element in the session was for the pupils to agree on what content to draw (see image 16). They did so with varying results. During the first session some groups had one pupil who decided and the other pupils followed their directions. In one group a pupil struggled with joining the other pupils in drawing but was encouraged by the pupils in his group. In the following sessions the pupils seemed to agree more easily which can be a result of smaller groups with two or three members instead of four or five. In the third session, where all groups consisted of two members, most of the groups started off by discussing what they would draw.

*"We kind of start to talk and then we see if we both like the idea"  
- Pupil at Hill School*

Many of the groups made compromises where they were able to agree on content by finding a way to combine their ideas. Disagreement is one of the activities described by Dillenbourg (1999, p.1-20) that trigger learning mechanisms. This is also supported by Howe & Zachariou (2017) that state that difference of opinion results in individual cognition and growth. This was defined as both a match and a mismatch between the pupil and group. It was, on the one hand, defined as a mismatch because the compromise led to the pupils not being completely happy with their idea. On the other hand it is defined as a match as it allowed the group work to continue in a productive manner. However, some groups were instead able to build on each others' ideas to create something they were more happy with. This was therefore defined as a match between pupil and group.

*"Ice cream?" "Cake?" "Ice cream cake!" (...) "And there can be candles on it"  
- Three pupils at Forest School building on each others' ideas*

During session two and three the pupils stated that it was difficult to come up with what the landscapes should look like. In some groups this was also noticeable as pupils asked their team members what they were going to draw instead of trying to come up with an idea together. Other pupils simply started drawing to see where it would end up. This was interpreted as that the pupils needed a more specific goal to be able to agree on content more easily.

*"No it was not difficult to agree. We kind of just started drawing"  
- Pupils at Forest School*

### 5.3.2 Esthetical

A significant part of the session was focused on the pupils' esthetical preferences. Here, the insight gathered from the pupils' characters, landscapes and rewards are presented.

#### Character

Three main types of characters were identified; humans, animals, and fictional characters where the vast majority of the groups (22 out of the 25) had created at least one human character (see image 17). The second most popular characters to draw were fictional characters which included anything from aliens to more freely drawn appearances. Finally, the smallest category were the drawings that depicted animals such as cats and foxes.



Image 17: Summary of the pupils' drawings of characters.

## Bag

When it came to deciding what the character should bring with them in their bags the pupils have been very practical in their choices. The most popular thing to draw was food such as fruit or bread closely followed by clothes where t-shirts were commonly found. Other frequently drawn objects included sport products, pets and teddy bears which were categorised as hobby products (see image 18). Further, necessities such as hygiene articles were popular among the pupils and many included toothbrush and toothpaste in their packing. Finally, pupils also drew money, digital devices such as smartphones or tablets, drinks, and more adventure themed items such as weapons and torches. None of the drawings that the pupils made and that the authors were able to interpret, included fictional elements.

*"Here is a toll and they need to pay to pass, if you look at the character they have money"*  
- Pupil explaining the benefit of their character having money in the bag



Image 18: Summary of the pupils' drawings of bags



Pupils drawing a landscape together



## Landscape

The landscapes made by the pupils varied greatly in appearance and were divided into two main categories; realistic and fictional (see image 19).

The realistic landscapes mainly included animals and elements of nature such as forests, rivers, meadows, and beaches. Further, some of the pupils drew existing faraway places such as Hawaii, Singapore, Africa, and Mars. Other pupils were more focused on creating something mathematical and drew worlds that included for example a mathematical museum and mathematical games. In total there were 28 significant realistic elements in the landscapes that the pupils created.

*“To tame one monkey you need two bananas. If there are five monkeys how many bananas do you need to tame them all?”  
- Pupils at Forest School*

The fictional elements in the landscapes commonly included classic story features such as witches and werewolves or the pupils’ own fictional characters like monsters or fictional animals. Others made landscapes for characters from other stories such as Peppa Pig and Harry Potter. Some pupils created worlds made up of sweets and some created landscapes that were split into opposites such as night and day and lava and ice. Finally, some pupils were more innovative and created landscapes such as an outer space laser fight between alien crabs which also included the Illuminati. Another example is a landscape including Jesus and his hand who is controlling everything including wizards, fire trucks, pike fish and frogs. In total 23 fictional elements were found in the pupils’ drawings.

*“She wanted a rainbow world, I wanted a candy world. So it is a candy rainbow world”  
- A pupil at Hill School*



Image 19: Summary of the pupils’ drawings of landscapes

## Award

When the pupils were asked to come up with an award that the characters could share after their journey the most common award was some kind of snack (see image 20). The snack could for example be sweets, ice cream cake, or cinnamon buns. Some of the findings that were harder to categorise were the group who decided that their characters were awarded a fifa game and the group that created a mathematically themed award. To summarise, 16 of the awards were of a mainly realistic nature.

*“Say all the things you know about math”*

*- A pupil at Forest School trying to come up with an award related to mathematics*

Furthermore, the pupils also created awards that were more fictional. These included for example, a magic necklace, the heart of Smaug (a dragon from the film series the Hobbit) and gigantic toilet paper rolls. Others were more traditional and their characters found some kind of treasure as a reward. These treasures were most commonly filled with jewels and gold. In total, 10 of the awards had fictional elements.

*“It’s a necklace that you can turn and wish for anything you like”*

*- Pupil at Forest School explaining their drawing*

## Award



Image 20: Summary of the pupils' drawings of awards.

The results of this participatory session pointed to that the pupils preferred mainly realistic content with fictional elements.

## 5.4 Discussion and Implications

The process of the participatory session and the analysis of the data is discussed below. The main insights from the session are summarised under implications.

### 5.4.1 Discussion

While the authors tried to make the material for the participatory session as open as possible there is still a risk that the pupils have been subconsciously guided by the material or the way it was presented. Furthermore, the teachers announced the sessions to the pupils before the authors arrived and how it has been presented can have caused biases within the pupils. The variety within the pupils' creations does however indicate that this has not had a significant impact on the results.

During the first part of the sessions the pupils were asked to draw within the bag what they wanted the characters to bring on a journey. As can be seen in the result the pupils chose many practical items such as hygiene products or food. This is not believed to translate one to one to what pupils would want a character to carry in a concept.

As mentioned above, the authors had problems interpreting some of the pupils' drawings. The drawings that the authors were unable to interpret have been excluded from the results which creates an error margin in the results. Furthermore, there is a chance that drawings have been misinterpreted. However, the authors were present during the sessions and the combination of the drawings and the notes that were taken gives assurance that no major misinterpretations have occurred.

### 5.4.2 Implications

- Starting with an additive assignment worked well for the group dynamics.
- The pupils struggled to handle disagreement constructively.
- The pupils need support to create arguments.
- When the pupils successfully collaborate they are able to build on each others' ideas and knowledge.
- Pupils enjoy creative freedom.
- Pupils appear to prefer mainly realistic characters and landscapes.
- Further, pupils appear to be concerned with practical aspects such as access to food.

When continuing on to the next phase it was evident that further data was needed on esthetical preferences. As it was impossible to judge what idioms, i.e. style, pupils prefer this had to be evaluated in the following phase. Additionally, material that provided the pupils with more support to handle disagreements and formulate arguments had to be designed and evaluated.



**Formative  
evaluation**

**Aim**

**Method  
&  
procedure**

**Collage**

**Ideation**

**Formative  
evaluations**

**Analysis**

**Discussion  
&  
implications**

**Reasoning  
about  
assignment**

**Agreeing on  
content**

**Result  
&  
analysis**

**Solve problem  
collaboratively**

**Esthetical**

# 6. Formative Evaluation of Idioms and Assignments

The purpose of this phase was to enable the pupils to share their opinions and experiences of the material that the authors had created and for them to give feedback on how it could be further developed. This was done by performing formative evaluations with 12 groups of pupils. The phase builds on the knowledge from the previous phases such as the pupils' preferences regarding storyline and characters and their abilities to collaborate and difficulties to form arguments. The evaluations were designed to evaluate four idioms and how well the material could guide the pupils into forming arguments and handle disagreements. The data regarding the idioms were analysed by categorising the pupils selections and quotes to understand the pupils' esthetical preferences. Further, the data regarding the collaboration aspect was analysed with the activity system model to find mismatches and matches.

## 6.1 Aim

This phase had two aims; to evaluate ideas on how collaboration can be mediated by the material and evaluate the pupils' esthetical preferences. The collaborative aspects mainly regarded how the assignments could be constructed to enable collaboration. The esthetical preferences regarded idioms and the storyline.

## 6.2 Method & Procedure

This chapter described the methods used during this phase of the project. In the formative evaluations the pupils calculated mathematical problems together and gave their opinion on visual material. The educational aspects were analysed with the activity system model and the esthetical aspects were analysed by categorising quotes that were compared to quantitative data.

The authors created collages for internal communication on visual expression and ideated on the content for the formative evaluation. The evaluation itself was conducted in two schools during after school care. The esthetical and educational results were analysed and presented separately.

### 6.2.1 Collage

A collage was made for internal communication between the authors with the purpose of creating a definition of what expression the graphical elements and final design should have (van Boeijen et al, 2013, p. 93).

### 6.2.2 Ideation

With the purpose of creating a wide range of ideas the authors worked with brainwriting and brain drawing where ideas for how the session could be constructed were created in a positive and encouraging environment (van Boeijen et al, 2013, p. 119). The authors decided on certain elements that would be included in the evaluation such

as mathematical problems, agreement, argumentation, and explanation and built the workshop around these elements. Inspiration was taken from what had worked well in the participatory session.

### 6.2.3 Formative Evaluation

A formative evaluation was conducted during lessons at after school care at two schools (see image 21). This means that the evaluation was conducted with the purpose of gaining insights that help develop the material further. The purpose of the evaluation was to further explore what type of idiom, i.e. visual style that appeals to the pupils. It was constructed in the form of group work to enable testing of ideas regarding collaboration and also to test the pupils' ability to explain to one another. The authors individually conducted the evaluation with groups of two pupils at a time. During the evaluation the authors explained the assignments to the pupils according to a prepared script and took notes on the pupils interactions with each other and the material. For each part of the evaluation the authors had prepared questions to ask the pupils. See appendix F for script and questions. The result from the previous session showed that the pupils had varying interests and ideas on how the interface of the tool should be visualised. The idiom of the pupils drawings was however difficult to evaluate due to their drawing skills. To evaluate the pupils preference four illustrations with different idioms were created based on the discussions of the pupils. These idioms were; realistic, scary, cute, and geometrical.

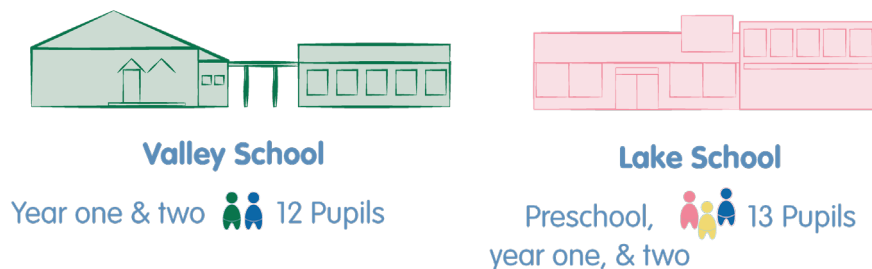


Image 21: Illustration of the visited schools. The illustrations of children indicate maximum group size.

# FORMATIVE EVALUATION

In this evaluation the pupils gave their opinion on different visual styles and solved mathematical problems with visual support.



## 1. Introduction

The authors presented themselves and explained why they were doing the session and how it would work.

The aim was to:

- explain the purpose to the pupils
- make the pupils feel comfortable

## 2. Selection of Parrot

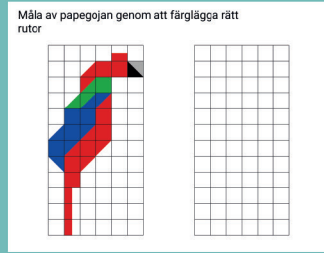


The pupils were given a paper with four parrots designed with different idioms. They were to select one of the parrots that they preferred and were asked questions of why they made the choice they did.

The aim was to:

- explore what idioms pupils prefer

## 3. Drawing Parrot

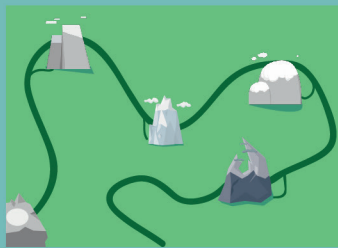


The pupils were given a simplified image of a parrot in a grid system made out of coloured squares. Further, they were given a sheet of paper with a "clean" grid system that they were to fill in to replicate the parrot. The pencils with the colours needed to replicate the parrot were divided between the pupils and they were not allowed to use each other's pencils. They were prompted to collaborate to paint the parrot and once they finished the assignment they got the parrot they selected in the shape of a game

The aim was to:

- explore what happens when both pupils have to contribute
- explore if this type of assignment promotes explanation
- and if so, explore how pupils explain to each other

## 4. Selection of Mountain

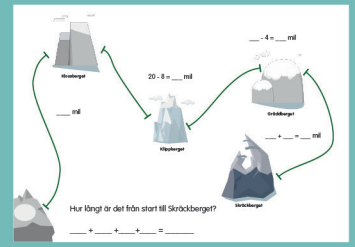


The pupils received an image of a landscape with four mountains that were connected with a road. Further, they were given two game pieces representing themselves. The pupils were then asked to select a mountain they wanted to go to and were asked questions of why they made the choice they did. Depending on what mountain they selected the parrot would let them know that it thought it was too far away or too close to home. The pupils would then be asked to answer what other mountains they could go to instead.

The aim was to:

- gather further information on what idioms pupil prefer
- explore if and how their choice is related to context

## 5. Calculating Distances



The pupils received a map where they were to calculate the distance between the mountains. The distances were calculated with addition and subtraction. Finally by adding all the distances they were able to calculate how far it was from start to the mountain furthest away.

The aim was to:

- evaluate how much visual support the pupils need
- explore how pupils use visual support
- observe how pupils work with an assignment that does not require all group members to participate

## 6. Reflection

To sum up the formative evaluation and gather input from the pupils the designers asked the pupils what they thought of the assignments.

The aim was to:

- understand what the pupils thought of the session
- understand how the session could be further developed

## 6.2.4 Analysis

After the evaluation the authors transcribed the notes and organised the quotes in a table so that an overview of the pupils comments on each illustration could be seen. Further, the pupils' choices were counted and summarised in the table. In order to maintain knowledge on which group said what, they were assigned a number and a letter. The groups who tested with one author were called for example 1a and the groups who evaluated with the other author were called group 1b. This way the authors could ensure that data from all the groups were included without compromising anonymity. The transcribed data which was related to collaboration and mathematics was analysed through discussion and searching for patterns between the groups. These insights were later presented in the activity system model.

## 6.3 Result & Analysis

The insights from the formative evaluations were analysed with the activity system model and by categorising quotes. The activities and their mismatches and matches regarding the educational aspects are presented in the first section. These are followed by the results from the esthetical evaluations.

### 6.3.1 Solve Problem Collaboratively

As in the participatory session, the main activity was defined to be Solve problem collaboratively (see image 22).

In this formative evaluation it became further evident that an additive assignment allows all group members to contribute from the start. The additive format of the assignment is considered to be a match between the division of labour and object, since the work was divided between the pupils and they could both learn how to solve problems and collaborate. By providing the pupils with different colour pencils the division of labour was clear and even the pupils who seemed shy were encouraged to participate.

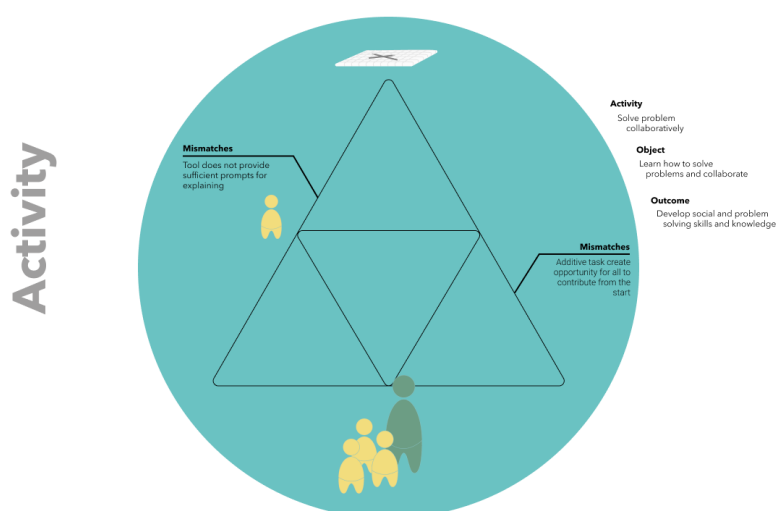


Image 22: Activity system model of solve problem collaboratively.

A mismatch was found in that the material did not provide sufficient prompts for explaining, meaning that on many occasions one pupil would perform the calculations without involving the other pupil. In some groups where the difference in educational level of the pupils was high the younger pupil would state that they understood everything and that it was easy even though it was evident that they had not contributed.

*"I think, this one is that one"*  
*"Good, we start with the beak"*  
*"Nice, very good"*  
 - Pupils at Valley School

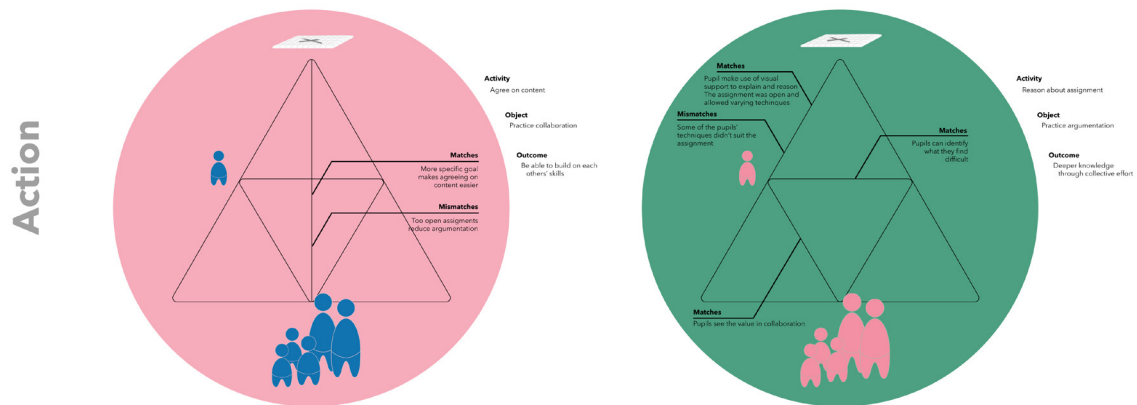


Image 23: Activity system model over the two actions.

### 6.3.2 Agreeing on Content

Within the action Agreeing on content it could be seen that the formulations of the assignments did not provide the pupils with enough information for them to construct arguments on their preferences (see image 23). When some groups chose which parrot they wanted, the assignment lacked factors that could help them argue for which mountain was best for the assignment. Most pupils were however, able to state their preference and explain why they liked it but when the group disagreed they struggled to come to an agreement. This is defined as too open assignments reduce argumentation and is considered a mismatch between the group and evaluation material.

### 6.3.3 Reasoning About Assignment

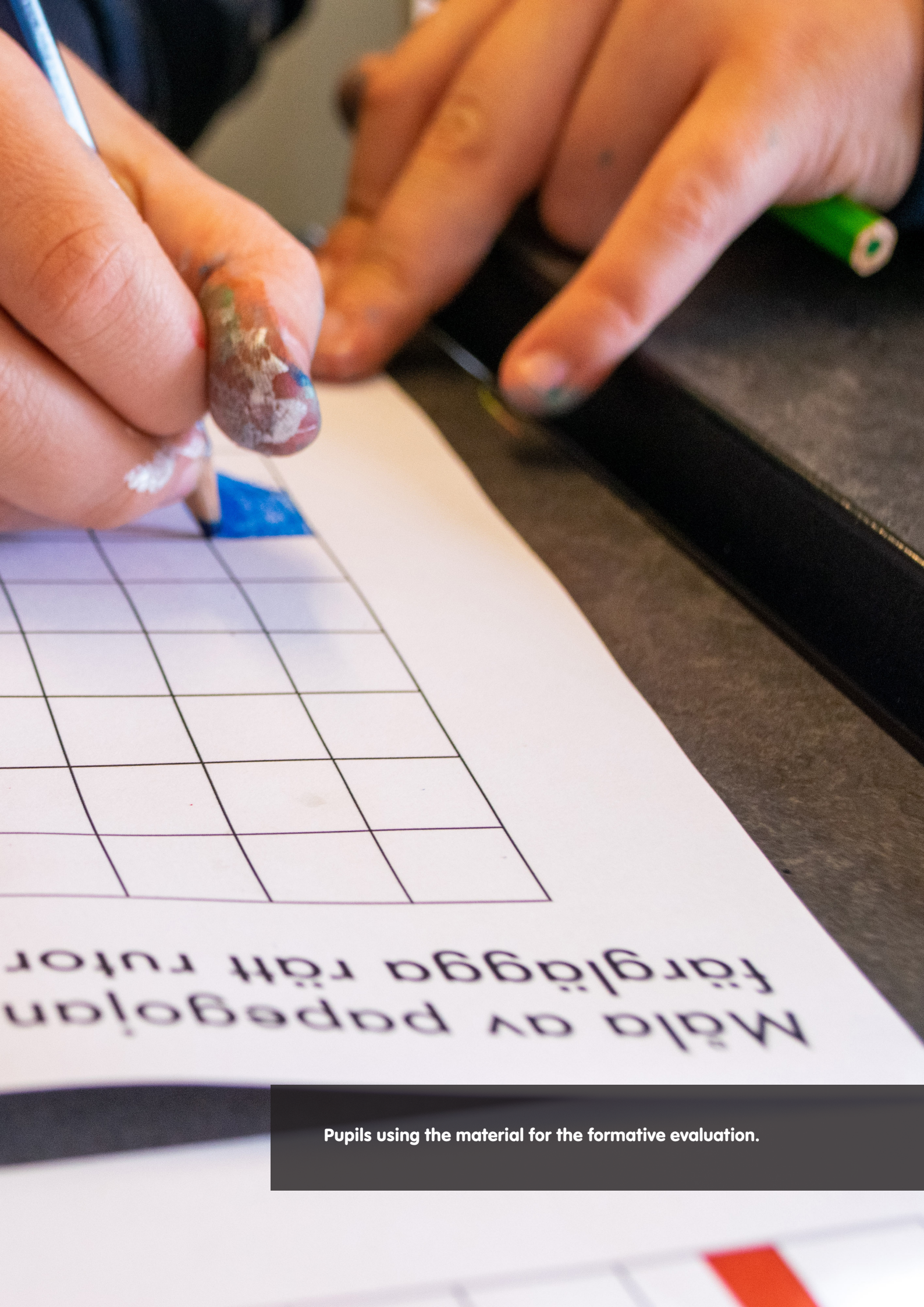
A key element in the evaluation was for the pupils to reason about the assignment and several matches and mismatches occurred within this action.

Firstly, a match was found between the pupil and the group as the pupils were considered to see the value in collaboration (see image 23). They talked about how they could learn from each other and ask each other for help.

*"The other person often knows more.."*  
*"...and you know different things."*  
 - Pupil talking about collaboration at Valley School



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Pupils using the material for the formative evaluation.



Image 24: Pupils filling in answers.

Continuing, it was considered to be a match between pupil and object that the pupils could identify what they find difficult. This is defined as a match because it allows the pupils to reflect on what is challenging to them and what they can practice more. As described by Illeris (2015, p.75-103) reflection is an important factor when processing knowledge and being able to transfer it to the everyday life.

*"The math was the most fun and the miles. You got a little challenge. It was tricky."  
- Pupils at Valley School*

Another match that was found was that pupils make use of visual support to explain and reason. They pointed to the material and in the first additive assignment some pupils counted the squares to explain to their group member where to draw. When they chose a parrot and mountain to climb some pupils made use of the visual information that they had to discuss the illustrations. They talked about whether it would be possible to climb the mountains based on their shape and if the parrot would be able to land on the mountains.

*"We can start from the top, right?"  
"You can paint one down as well"  
"Then I think we can paint the bill"  
- Pupils at Lake School*

Finally, the pupils were able to use the technique that they preferred to calculate the assignment as there were no instructions on how to perform the calculations. This is considered a match between the pupil and assignments as pupils vary in the learning strategies they use (Kajetski & Salminen, 2013, p.13). Some pupils calculated in their head, others wrote on the paper and some used their fingers. However, being able to

use any technique allowed for using approaches that didn't suit the assignment. There were for example pupils who tried to calculate larger numbers with support from their fingers and were unable to find the right answer. It is therefore considered a mismatch between the pupil and evaluation material.

*"Eight plus two, remove two from nine and then you have seven left"*  
*-Pupils at Lake School on how to calculate eight plus nine.*

### 6.3.4 Esthetical

During the evaluation the pupils were asked to select and agree on their favourite parrot and mountain. The pupils were divided in groups of two, except for one group that consisted of three pupils. Due to some groups being unable to come to an agreement when selecting their favorites the result is presented by the number of individual pupils who selected each parrot and mountain.

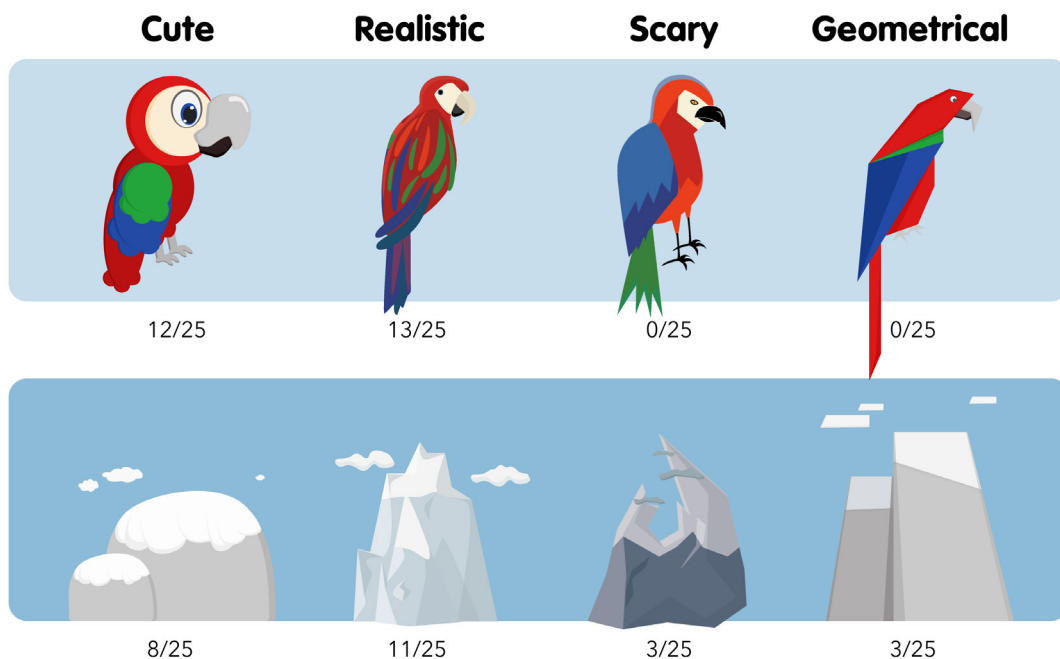


Image 25: visualisation of the pupils' preferences.

*"It has colour and looks like a regular parrot"*  
*- Pupil from group 6a about the realistic parrot*

A majority (13 out of 25) of the pupils selected the realistic parrot as their favourite. The reason behind their choice differentiated but several pupils stated that it was because it looked the most similar to a real parrot and that it was colourful. 12 out of 25 pupils preferred the cute parrot, which was the second highest result. The pupils who voted on this parrot considered it to be cute and unrealistic.

*"I think it should be that one because it is the cutest"*

*- Pupil from group 2a about the cute parrot*

No one preferred the geometrical parrot and it was described as square, papery and resembling minecraft. The scary parrot did not get any votes either and when asked what pupils thought about it they described it as grumpy, weird, cranky and angry.

*"It does not look real. It is like it is made out of shapes and a parrot is not really made out of shapes."*

*- Pupil from group 3a about the geometrical parrot*

It was found that few pupils had negative feelings towards the realistic parrot even if they did not vote on it. The few negative comments that concerned it was about it not having legs and that the feathers were difficult to see. However, the pupils who did not vote for the cute parrot had stronger negative attitudes towards it. It was described as looney, unrealistic, too big beak and weird.

*"It looks the most normal, like Mount Everest"*

*- Pupil from group 2b about the realistic mountain*

The majority (11 out of 25) chose the realistic mountain as their favorite. They described it as realistic, big and adventurous. The cute mountain got the second highest rating (8 out of 25) and was described as round, unrealistic, and fluffy. Both the scary and geometrical mountain got 3/25 votes each. The geometrical mountain was described as square, flat, made out of blocks, and unrealistic. Exciting, dangerous, cool, creepy, scary, and dark were words used to describe the scary mountain.

*"It looks more like blocks"*

*- Pupils from group 4a about the geometrical mountain*

When selecting the parrot the pupils discussed its appearance and only one pupil talked about its traits such as the big eyes could enable him/her to see far away. However, when selecting the mountain many of the pupils were thinking of its qualities. They discussed whether the parrot would be able to land on the mountain or if they themselves would be able to climb it. Some of the groups also started to discuss how well the parrot and the mountain would fit with each other regarding the visual aspect.

*"Fluffy and bent...no climbing stuff. It's not so high but hard to get up on"*

*- Pupil from group 6b about the cute mountain*

In both the selection of the parrot and the mountain the majority voted for the realistic mountain. Interestingly some pupils used the word unrealistic as a positive attribute whereas for others it was negative. In the previous participatory session and during the observations the pupils were often complimenting each other on their drawings. It was found that the pupils were impressed with other pupils who could draw the closest to reality.

## 6.4 Discussion and Implications

The process of the formative evaluation is discussed below and the main results of it are summarised under implications.

### 6.4.1 Discussion

The author's presence can have impacted how the pupils behaved during the test. As the groups consisted of only two pupils the presence of the author who led the evaluation can have been perceived as a stronger presence than in the participatory sessions. The authors aimed to reduce the risk by emphasising that the pupils were the experts of their experience and that notes were taken to remember the pupils' smart statements, not to evaluate them.

As this evaluation was conducted at after school care the pupils who volunteered to participate can have been extra interested. This may have impacted the result of the evaluation to not be entirely representative for all pupils. However, during the evaluations there was no indication that all participating pupils were, for example, high-achievers or especially interested in design.

With the purpose of making the evaluation feasible to conduct and possible to analyse only four idioms were illustrated. Although these were based on insights from previous phases it is possible that the pupils prefer a different idiom or mix of two idioms.

### 6.4.2 Implications

- The pupils prefer illustrations with realistic proportions.
- The pupils are concerned with practical aspects.
- The pupils need clear information to be able to construct arguments.
- The pupils see value in collaboration.
- The pupils make use of visual support to explain and reason.
- It is positive that the pupils can make use of a variety of learning techniques.
- It is negative when pupils use learning techniques that are inappropriate for the assignment.

In the following phase the authors used the results presented with the activity system model to create guidelines, and in turn, two concepts. Furthermore, to ensure that the authors had understood and interpreted the pupils accurately there was a need to evaluate the concepts.

**Guidelines**

**Aim**

**Method  
&  
procedure**

**Educational  
guidelines**

Explanation of  
twelve guidelines

Explanation of  
nine guidelines

**Esthetical  
guidelines**

**Discussion  
&  
implications**

# 7. Guidelines

The purpose of writing guidelines was to create a theoretical foundation that could be utilised to create digital interfaces for collaboration in the classroom. These guidelines are based on the matches and mismatches that were identified in the activity system model in the previous phases. Two sets of guidelines were developed where the first is concerned with educational factors and consists of twelve guidelines. The second set encompasses esthetical factors and aspects that concern the storyline of the content.

## 7.1 Aim

The aim of this chapter was to create guidelines containing what should and can be taken into account when designing a digital interface for collaboration.

## 7.2 Method & Procedure

The educational guidelines were developed based on the matches and mismatches that have been identified with the activity system model. The matches and mismatches were rewritten to guidelines. The esthetical guidelines were mainly based on the pupils' esthetical preferences that were expressed in the participatory session and the formative evaluation. Each guideline is supported by should or can statements that indicate which statements are necessary to take into account and which statements are optional.

## 7.3 Educational Guidelines

In total, twelve guidelines were developed within the educational category. These guidelines are supported by explanations on how they should or can be implemented. In addition to what is stated in the guidelines it is important that the content of the interface is adjusted to the Swedish curriculum.

Based on the different group sizes that were tested in the participatory sessions and evaluations the guidelines have been mainly developed for collaboration in groups of two pupils. As not all classes are split evenly in two and as all pupils are not always present, the collaboration should also function for groups of three pupils.

### 7.3.1 Designed for Teachers

The first guideline is concerned with how valuable the teachers skills are and how the product can preserve and utilize these. The teacher is, of course, a key factor in education and has to a certain extent, the possibility to decide what tools are used during lessons and how. Therefore, it is important that the tool is easy to use for the teachers and provides them with additional value such as a possibility to correct assignments efficiently. In short, the tool should be designed with the aim of assisting the teacher rather than replacing them.

- The tool should be designed to assist the teacher in their work and utilize their skills.

This should be done by...

- ...encouraging the teacher to conduct group work in whole class sessions to avoid pupils without devices being distracted by devices used by other pupils.
- ...providing a tool that is easy to navigate for the teacher in order for them to find and assign correct assignments to pupils in a time efficient way.
- ... introducing and explaining the tool to the teachers since there are a large number of apps and it is difficult for the teacher to differentiate both subject and level.
- ... allowing the teacher to adapt the tool to different situations such as pausing and providing explanations to both full class and individual pupils.

This can be done by...

- ... enabling the teachers to overview the group's work so they can maintain knowledge of pupils' progress.

### **7.3.2 Lesson Time**

Secondly, the tool has to be designed with regards to the lesson time. The pupils work in varying paces and should for example have the opportunity to finish the assignment another day if they haven't completed it by the end of the lesson. Further, the tool needs to be adjusted to the fact that not all pupils are present at all lessons meaning that the group composition can change and the group size can vary between lessons.

- The tool should be adapted to the lesson time.

This should be done by...

- ... allowing for continuing the group work at another time if pupils don't finish during the lesson.
- ... providing the pupils with a sense of having finished the assignment to build confidence and clarify progress.
- ... allowing for a change of group composition between lessons as all pupils are not present at all time.

### **7.3.3 Clear Instructions**

Throughout the user studies in this thesis it has been evident that instructions are a key success factor in any assignment. The pupils need the instructions to understand what to do and how to do it and the teachers need clear instructions to further explain to the pupils and provide them with confirmation.

- The tool should provide pupils and teachers with clear instructions.

This should be done by...

- ... providing instructions in more than one formulation to increase the chance of all pupils understanding.
- ... in the instructions promoting inclusion of all pupils to encourage all pupils to participate.
- ... giving the teacher support to provide the pupils with instructions on how to use the tool since some pupils need confirmation or help.

#### **7.3.4 Eagerness to Learn**

The pupils that have participated in this process have proven to be very eager to learn and have a generally positive attitude towards school and education. This guideline is therefore concerned with preserving this attitude and curiosity, for example by celebrating progress and building self-esteem.

- The tool should maintain the pupils' eagerness to learn and their positive as well as curious attitude.

This should be done by...

- ... enabling celebration of pupils' progress to build confidence and team spirit.
- ... providing content that builds self-esteem which in turn can maintain motivation.
- ... motivating the pupils to understand and solve errors to promote understanding as more important than being right.

This can be done by...

- ... including fun features to evoke interest without crossing the line from education to entertainment as pupils might become distracted.

#### **7.3.5. Educational Methods**

The theory and user study has shown that pupils use and prefer different educational methods. The tool should therefore be designed so that the pupils can apply the method and internalise the knowledge in their preferred manner.

- The tool should encompass different educational methods and internalisation of knowledge.

This should be done by...

- ... adjusting the language to an appropriate level in order for the pupils to practice their language skills without compromising the pupils' ability to calculate.
- ... providing the pupils with visual support for both explaining and understanding.

- ... enabling learning with different learning approaches as pupils have varying preferences of how to process information.
- ... not limiting different learning techniques but guiding the pupils towards appropriate and helpful techniques.
- ... enabling repetition and allowing the pupils to deepen their knowledge.
- ... promoting the pupils' understanding of the link between abstract and concrete in mathematical problems.

This can be done by...

- ... allowing pupils to find new ways of working than intended to not limit their resourcefulness.
- ... mediating learning through rhythm as this is seen to be popular among the pupils.

### **7.3.6 Varying Prerequisites**

The pupils possess different skills and work at varying pace which has to be taken into account when designing the tool. Further, social factors have proven to be important as some pupils do not get along or get along too well and distract each other.

- The tool should be flexible to fit pupils varying educational and social prerequisites.

This should be done by...

- ... being flexible enough to work for pupils with varying knowledge and skill to enable learning over different levels.
- ... being adapted to pupils working and finishing in different time spans since the pupils work in different paces.
- ... limiting the pupils to levels of difficulties that are adjusted to their needs.
- ... enabling the teacher to create the group composition in order to avoid social factors interfering with learning.
- ... enabling the teacher to make use of their knowledge of pupils' prerequisites to create groups with a positive exchange of knowledge.

### **7.3.7 Gain & Maintain Focus**

A commonly recurring event in the classroom is when the teacher attempts to gain or maintain the pupils focus. This is also a factor that should be considered when designing the tool.

- The tool should be designed to gain and maintain the pupils' focus.

This should be done by...

- ... being designed to keep pupils interested and minimize distractions from non-educational content within the product.
- ... containing content that is designed to maintain attention and interest without distracting from learning.

This can be done by...

- ... making use of rhythm to create and maintain focus since this is already implemented in schools as a well functioning method.
- ... mediating a certain level of personalisation as this is highly interesting to the pupils, however the opportunities should be limited in order to avoid distractions.
- ... helping the pupils regain focus after a switch of activity as this is when the pupils often lose focus.
- ... simulating teacher presence since pupils are more focused when the teacher appears to overview them.

### **7.3.8 Promote Inclusion**

In order for the pupils to be able to exchange information and perspective, which is included in the used definition of collaboration, all group members need to be included.

- The assignments should be designed to promote inclusion of all group members.

This should be done by...

- ... encouraging all group members to participate in the problem solving.
- ... allowing all group members to engage with the content at the same time to avoid exclusion.
- ... promoting all pupils to contribute from the start to provide a good foundation for the group work.
- ... giving the pupils a sense of common goal in order for them to more easily discuss and agree.
- ... creating a sense of community and mutual ownership to increase the chance of all members contributing.
- ... being designed so that the pupils perceive the division of labour as just and fair as this has proved to be important to the pupils.
- ... being designed so that all pupils can equally contribute in filling in or presenting results as this is something that the pupils are practicing in their current group assignments.
- ... being designed to give the pupils as much workspace on screen as possible to avoid exclusion.

### **7.3.9 Communicate & Explain**

The pupils have shown good skills in communicating with each other, however they seldom gave explanations to problem solving. To encourage them to explain the tool should simplify this by guiding them step-by-step and by the use of drawings. Further, the tool should enable the pupils to discuss by providing them with open-ended questions and support to formulate arguments without limiting them to decide themselves when to discuss.

- The tool should encourage the pupils to communicate with and explain to each other.

This should be done by...

- ... mediating step-by-step explanations of educational content to increase understanding and aid when explaining.
- ... providing the pupils with support to handle disagreement and formulate arguments as this is challenging for the pupils.
- ... providing pupils with open-ended problems to encourage discussion.
- ... allowing pupils to draw and/or provide animated drawing as a form of explanation to help them reflect on their knowledge.

This can be done by...

- ... allowing pupils to discuss and come to a conclusion or understanding through a flexible format that gives them freedom to do this in their own time.

### **7.3.10 Sharing**

The pupils showed a great interest in sharing with their fellow pupils. Their openness and willingness to share with others should be mediated by the tool with concern to both their learning insights and progress.

- The tool should mediate and encourage sharing between pupils.

This should be done by...

- ... encouraging pupils to share learning insights to emphasise progress and help others to learn.
- ... mediating sharing progress since the pupils value it highly.

### **7.3.11 Constructive Feedback**

It is important that the feedback encourages the pupils to understand by giving constructive feedback or by giving them the opportunity to find the incorrect answer themselves. Further it is important with feedback on effort, therefore the tool should also be designed to fulfill this need. The pupils that encountered insecurity when selecting the assignments should also be taken into consideration so that they receive confirmation on working with the correct assignment.

- The tool should provide the pupils with constructive feedback on effort and performance.

This should be done by...

- ... providing the pupils with feedback on effort or encouraging pupils to give it to each other to motivate them to maintain or improve effort.
- ... supporting the pupils, providing confirmation, and minimizing insecurity when finding the right assignment.
- ... providing pupils with constructive feedback so they can learn from their mistakes and successes.
- ... encouraging the pupils to find their own errors to understand where the mistakes occurred and build on this knowledge.

### **7.3.12 Encourage Reflection**

Reflection has shown to be important to learning however it has been difficult to investigate whether they do this or not since it can be performed non-verbally. Therefore, this guideline aims to amplify the importance of reflection on failure and understanding.

- The tool should encourage reflection.

This should be done by...

- ... mediating reflection on failure and how it is valuable for learning.
- ... being designed to avoid guessing and instead encourage reflection and active choice.

## **7.4 Esthetical Guidelines**

Nine esthetical guidelines, which include visual appearance and storyline, were created. These are based on what the pupils have expressed that they like, what they have created, and the idioms that they preferred during the evaluation.

### **7.4.1 Colourful Expression**

When discussing the idioms presented in the formative evaluations a significant number of pupils preferred the illustrations that they found the most colourful. Further, the majority of the pupils created landscapes, characters and rewards that were colorful.

- The visual expression of the interface should be colourful as the pupils find this appealing.

### **7.4.2 Realistic Proportions**

The pupils have proven to be very concerned with the proportions of the visual support. When they discussed the idioms the pupils expressed negative attitudes towards the illustrations that were very square or unnaturally round.

- The visual expression of the illustrations should be realistic in its proportions and shapes to minimise risk of negative attitudes towards the tool.

### **7.4.3 Practical Aspects & Consistency**

When designing the storyline for the tool, it should be taken into account that pupils are attentive to practical aspects and consistency. For example, during the formative evaluation some pupils were concerned about which mountain the parrot could land on or how if it would be possible to climb the mountain.

- The visual interface and storyline should be designed with the fact that the pupils are concerned with practical aspects and consistency taken into account.

### **7.4.4 Consistent Storyline**

As all pupils are not present at all lessons the pupils should be able to follow the assignment without remembering the storyline of the previous lesson. It is however, important that the storyline is consistent so that it is easy to follow between lessons and does not provide the pupils with unnecessary new information.

- The storyline of the tool should be consistent without demanding the pupils to remember the previous assignments.

### **7.4.5 Elements of Individualisation**

It has been seen throughout the process that the pupils enjoy individualisation and that they take great joy and pride in creating their own content. As it can be very time consuming for the pupils to create content it is suggested that they also can edit content which could be done in a more confined manner.

- The interface can have elements of individualisation where the pupils themselves can create or edit content.

### **7.4.6 Visual Variations**

In the landscapes that the pupils created during the participatory session a lot of variations could be seen within the drawings. Some of them were split into two opposite landscapes or had elements of several different landscapes. Therefore, the landscape within the tool can allow for variations.

- The landscape within the interface can contain visual variations as this is something that frequently appears in the pupils' creations

### **7.4.7 Contain Animals**

A recurring element in the pupils' creations was that they drew a lot of animals. This could be seen both in the landscapes and in the characters. Further, during the observations the pupils commented extensively on cute animals that were included in one of the apps that they used.

- The visual expression and content of the storyline can contain animals as the pupils are fond of them.

### **7.4.8 Scary Elements**

While the pupils were intent on not wanting to go to the scary elements during the formative evaluation, they still expressed curiosity about them. In some of the landscapes that were created the pupils included scary elements that the characters had to avoid or overcome in their journey. It was therefore concluded that even if the tool should not be entirely based on scary visuals they can include elements of it.

- The interface can have elements that are considered to be scary to create interest.

### **7.4.9 Fictional Elements**

In a majority of the pupils' creations they had mainly realistic content, however, a significant amount also included fictional elements. Therefore, a balance is recommended where visuals are based on realistic illustrations with the possibility to include fictional elements.

- The visual expression of the interface and the storyline of the content can contain fictional elements as pupils find this interesting.

## **7.5 Discussion & Implications**

The number guidelines and to what degree it is feasible to implement them is discussed below. Furthermore, the guidelines are summarised under implications.

### **7.5.1 Discussion**

Some of the guidelines could be considered conflicting, such as allowing individualisation and limiting non-educational usage. This is however considered to be conflicting based on the current implementation of individualisation in the observed apps. When designing for the guidelines with regards to gaining interest from the pupils it is therefore important to be cautious and ensure that all elements are connected to the learning outcomes.

Finally, the esthetical preferences of the pupils are likely to be sensitive to trends within the age group and within the class. It is likely that the pupils are affected by characters and storylines that they encounter in different media. The results regarding the esthetical preferences are therefore considered to be sensitive to the passage of time. To further ensure the accuracy of the esthetical results further studies with more participants would have to be conducted.

## 7.5.2 Implications

This chapter presents two sets of guidelines that concern the educational and esthetical factors of enabling learning together through a mediating, digital interface.

The educational guidelines are as follows:

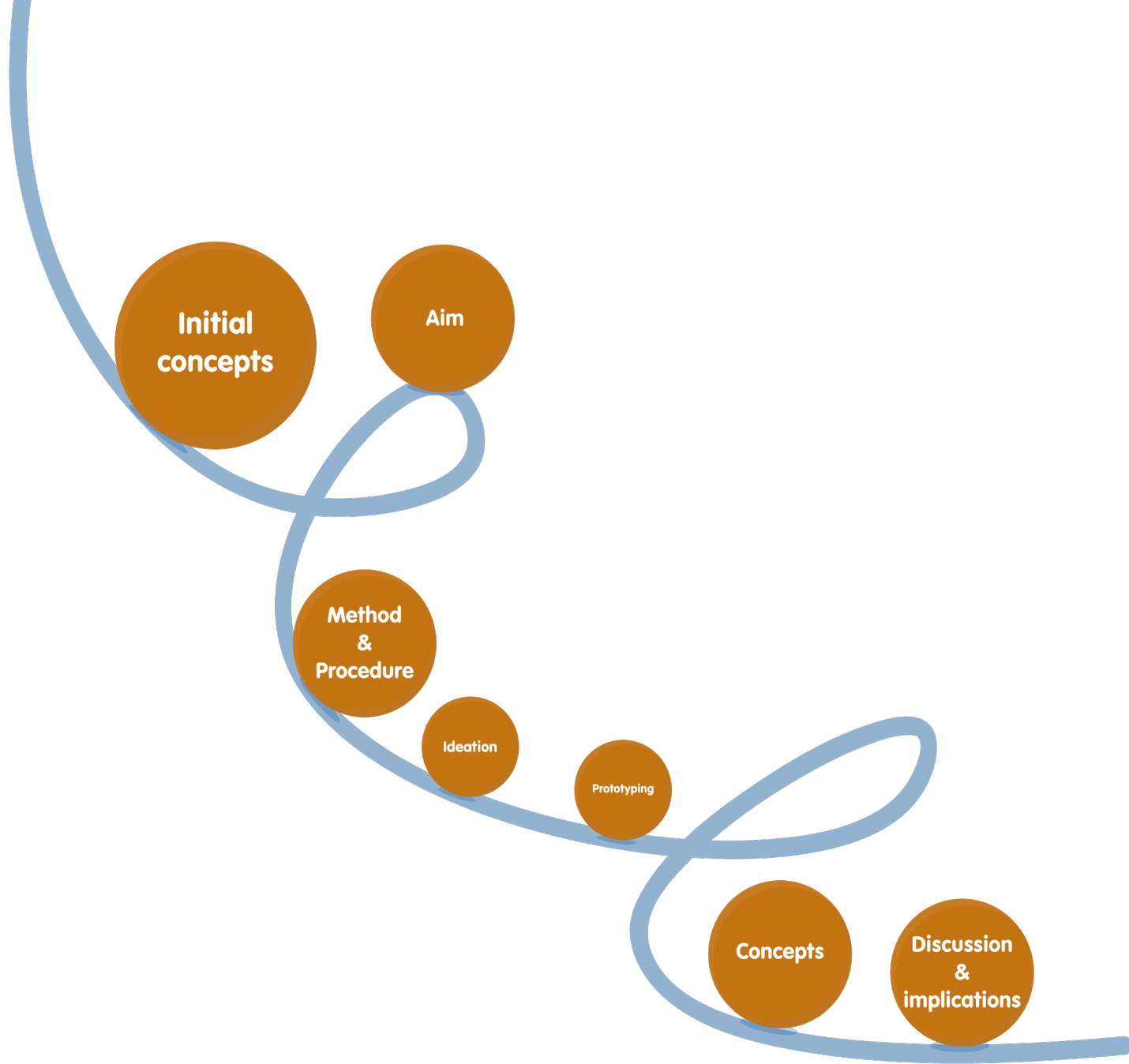
1. The tool should be designed to assist the teacher in their work and utilize their skills.
2. The tool should be adapted to the lesson time.
3. The tool should provide pupils and teachers with clear instructions.
4. The tool should maintain the pupils' eagerness to learn and their positive as well as curious attitude.
5. The tool should encompass different educational methods and internalisation of knowledge.
6. The tool should be flexible to fit pupils varying educational and social prerequisites.
7. The tool should be designed to gain and maintain the pupils' focus.
8. The assignments should be designed to promote inclusion of all group members.
9. The tool should encourage the pupils to communicate with and explain to each other.
10. The tool should mediate and encourage sharing between pupils.
11. The tool should provide the pupils with constructive feedback on effort and performance.
12. The tool should encourage reflection.

The esthetical guidelines are:

1. The visual expression of the interface should be colourful as the pupils find this appealing.
2. The visual expression of the illustrations should be realistic in its proportions and shapes to minimise risk of negative attitudes towards the tool.
3. The visual interface and storyline should be designed with the fact that the pupils are concerned with practical aspects and consistency taken into account.
4. The storyline of the tool should be consistent without demanding the pupils to remember the previous assignments.
5. The interface can have elements of individualisation where the pupils themselves can create or edit content.
6. The landscape within the interface can contain visual variations as this is something that frequently appears in the pupils' creations.
7. The visual expression and content of the storyline can contain animals as the pupils are fond of them.
8. The interface can have elements that are considered to be scary to create interest.
9. The visual expression of the interface and the storyline of the content can contain fictional elements as pupils find this interesting.

In the following chapter concepts were developed based on the guidelines above to evaluate how the guidelines could be implemented.





# 8. Initial Concept Development

The purpose of this chapter was to use the guidelines presented in chapter 7 as a basis for concept development. This was done by selecting guidelines that were important to fulfill the definition of collaboration and feasible to implement in a prototype. Continuing, the chosen guidelines are the ones that are most relevant to the interaction with the interface during lesson time. The results are organised after relevant guidelines and presented in text and images.

## 8.1 Aim

The aim was to develop two initial concepts that could be evaluated by pupils and compared to each other, thus generating results that could be used to develop an illustrative concept.

## 8.2 Method & Procedure

This part of the chapter described the methods used during this phase of the project. The concepts were developed through ideation and prototyping.

### 8.2.1 Ideation

The authors used brainwriting and brain drawing to generate a wide range of ideas. The ideation sessions were divided into categories from the guidelines to ensure that the concepts would take all of them in consideration. The authors first ideated on their own and then explained and discussed the ideas with each other. The ideas were chosen to create two concepts with clear differences regarding the three parts of the concept, i.e. introduction, main part and concluding part. From previous phases it was shown that it was difficult to get the pupils to explain to and discuss with each other. One of the focus areas in the ideation was therefore, solutions that could enable the pupils to discuss and explain more often and in more depth. Further, it was of interest to ideate around how reflection about failure could be implemented and how the design could enable inclusion by including all pupils from the beginning. Ideation regarding the visual support was also of importance since the visuals in the concepts should contribute to both learning and interest.



Image 26: Some of the drawings from the ideation on guidelines.

## 8.2.2 Prototyping

The concepts were illustrated in Figma and Adobe Illustrator and imported into a slide show. In both of the concepts it was of importance that the pupils could write the answers themselves and not select between multiple choices. As the prototyping programs did not allow for this function, the concepts were complemented with A3 paper sheets where the pupils could fill in their answers. The illustrations were presented in slides that the pupils could navigate back and forth with. The focus of these concepts was to test how the tool could help the pupils to collaborate and not the usability of a new digital product. Therefore, the navigation of the concept has not been designed nor evaluated.

To continue the development, guidelines which were feasible to test and conceptualise were chosen. As the esthetic guidelines are sensitive to trends and personal preference, it was decided that both concepts should be based on the same visual landscape.

Two versions of each concept were prototyped, one for first year pupils and one for third year pupils. These were very similar but the version for first year pupils contained less text and more simple calculations (see image 27).

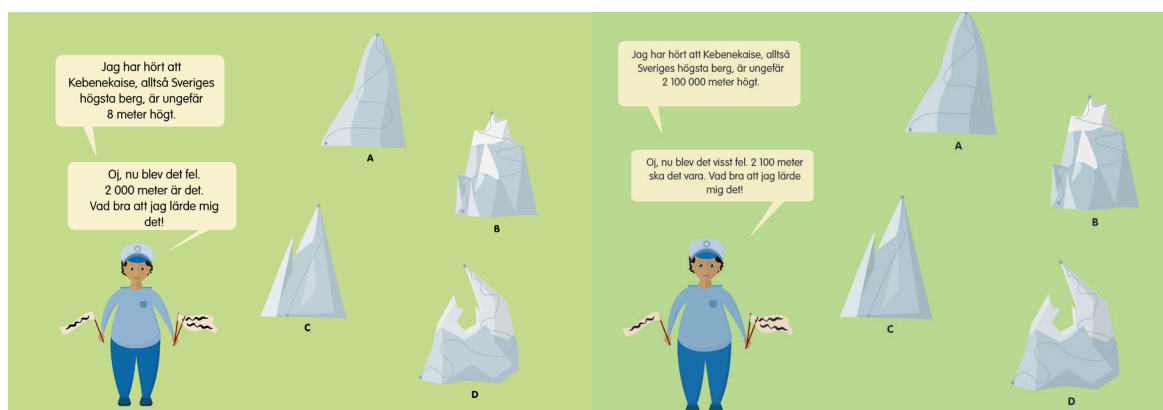


Image 27: Two versions of the same concept, the left is for year one and right for year three.

## 8.3 Concepts

The two concepts are built around the same landscape and the same structure with an introduction, main part including the mathematical assignments, and a concluding reflective part. The main differences between the concepts are explained in the section below and the details to each concept are described under each of the guidelines. The two concepts are named Llamath and Mathy.

Llamath is designed to enable the pupils to repete and practice the knowledge they already gained by solving problems in the mathematics book (see image 28). This concept aims to allow the pupil with a higher level of knowledge to learn by explaining and the pupil with lower level of knowledge by observing. The main parts of the assignment are, therefore, of a closed nature with a correct answer. However, two of the questions are of an open nature to encourage discussion between the pupils and create a deepened learning. The assignments connect concrete and abstract mathematics by allowing the

pupils to calculate on existing objects. In this concept the pupils get to follow and help the llamas Llamali and Llamama on their adventure to climb a mountain. The pupils practice measurements such as distance, time, and temperature.

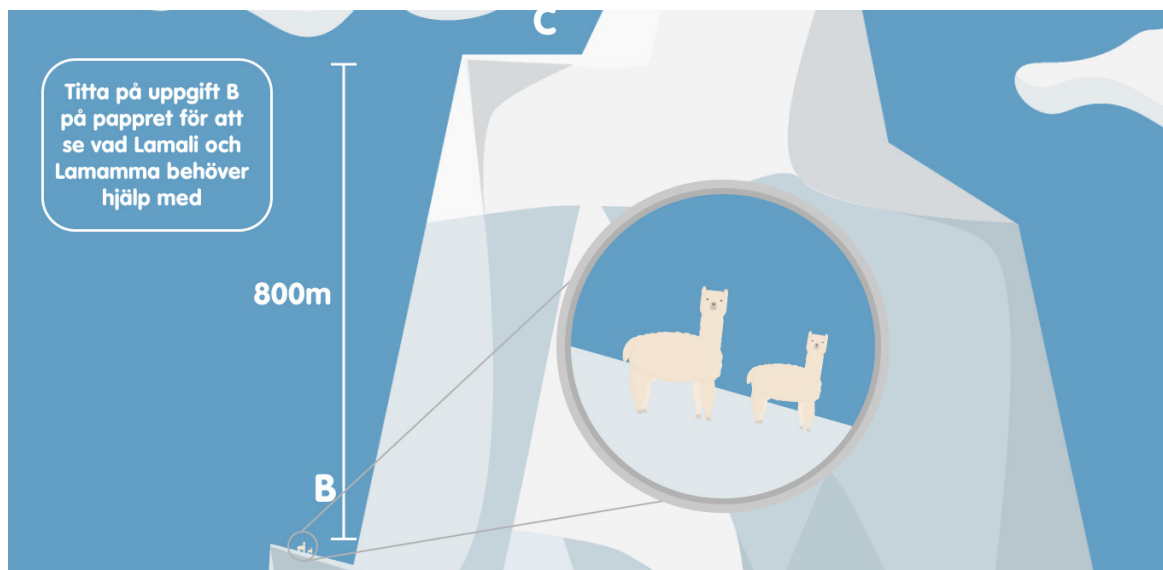


Image 28: A visual from Llamath saying that the pupils should solve assignment B.

Mathy is designed to enable the pupils to deepen their learning by discussing and arguing with each other (see image 29). The questions are also connected to their previous knowledge gained from solving problems in the mathematics book, but to encourage discussion and reasoning, the questions are of an open nature without a single correct answer. The pupils with a high and a low level of knowledge in mathematics should, therefore, be able to participate in the assignment on the same terms. The assignments are concrete and closely connected to everyday life by also encouraging the pupils to contribute with their knowledge gained from other subjects or their skills gained by practice. In this concept the pupils are introduced to the character Mathy, the captain of calculation errors, who is about to climb a mountain. The pupils get to practice plausibility with regards to distance, time and temperature.



Image 29: A visual from Mathy asking the pupils to discuss heights.

### 8.3.1 Clear Instructions

Llamath provides the pupils with instructions of the importance of including all members in the group work. This is done with a short reminder in the beginning of the assignment and it is also reflected in the characters who have to collaborate to achieve their goal of climbing the mountain (see image 30).

In Mathy the additive assignment in the first part of the assignment aims to motivate the pupils to participate equally. Further, the character encourages the pupils throughout the assignment and gives instructions.

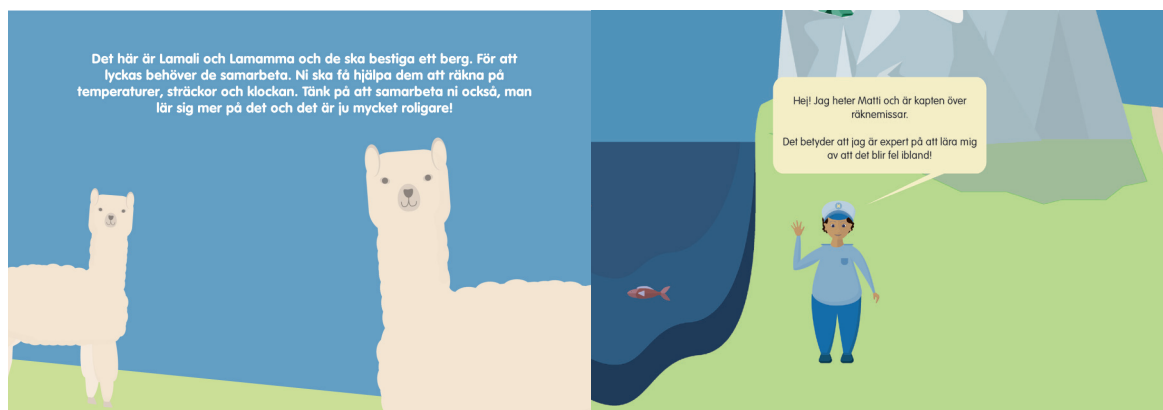


Image 30: Introduction screens of Llamath (left) and Mathy (right).

### 8.3.2 Eagerness to Learn

The characters in the Llamath will encourage the pupils and celebrate their progress of the assignment. The llamas will simulate the pupils' progress by taking one step further towards their goal after each successful assignment done by the pupils. The llamas are at the end of the assignment placed on top of each other and the pupils are asked to calculate how many llamas that have to be placed on top of each other to be as high as the mountain (see image 31). This is considered to be a fun feature but it is directly connected to the mathematics assignment and hopefully won't cross the line to entertainment. The pupils are also asked to write something they think the other pupil is good at on a chocolate bar at the end of the assignment.

In the final part of Mathy, the pupils are allowed to celebrate together (see image 31). The assignment is constructed with continuous encouragement and allows the pupils to collect trophies with praise from their fellow pupils. As the assignment encourages reflection on each answer by providing real life examples the pupils are able to discover on their own if their answers are realistic without being told that they are wrong. By including animals and a character in the assignment as well as a clear storyline the aim is to evoke the pupils interest.



Image 31: Encouraging aspects of Llamath (left) and Mathy (right).

### 8.3.3 Educational Methods

Llamath includes thermometers and clocks which will give visual support to the pupils and allow them to use it to both understand and explain to each other (see image 32). The learning techniques will not be limited and the pupils are themselves in charge of deciding on how to calculate. The assignments are related to concrete mathematical problems and there are no assignments that are solely abstract, however to solve the concrete problems abstract mathematics is necessary.

The open-ended questions in Mathy allow the pupils to apply the learning technique that they prefer such as drawing or writing (see image 32). The nature of these questions does however make it difficult for the pupils to count on their fingers as the numbers are high. By applying their mathematical skills on a realistic example the pupils are able to judge whether their answers are reasonable.

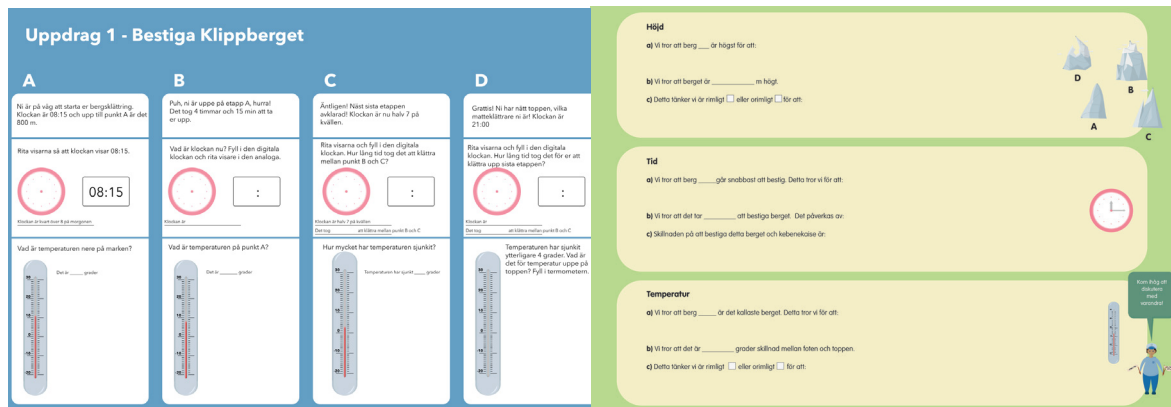


Image 32: The answer sheets of Llamath (left) and Mathy (right).

### 8.3.4 Varying Prerequisites

In Llamath there are varying levels of difficulty within the assignment and all pupils should be able to solve some of the problems. By mixing the level of difficulty the hope is that the pupil with higher skills can help the pupil with lower skills by explaining how they think. The assignment will only have one difficulty level which will increase for each

step. This will be correlating to the mathematics book and sum up the chapter they have learned most recently.

As the assignment in Mathy does not have any distinctly right or wrong answers the pupils can apply the level of knowledge that they have and build on it. The pupils who have a high level of knowledge can elaborate on their thoughts or specify the answers further.

### **8.3.5 Gain & Maintain Focus**

The characters in Llamath were designed to create interest, they fill functions such as prompting the pupils to discuss with each other and simulating the pupils' progress and will therefore hopefully not distract them from learning. In the beginning the app will count down, which is regularly used in the schools visited to gain focus from the pupils (see image 33).

The animation which is shown immediately makes use of rhythm as the bubbles leave the screen with even time spans (see image 33). Mathy allows for personalisation in the sense that the character carries the flags that the pupils choose and that they are allowed to formulate the positive feedback that they give to their group partner.



Image 33: The animations in Llamath (left) and Mathy (right).

### **8.3.6 Promote Inclusion**

The common goal is given to the pupils in the beginning of the problem - they are to help the llamas climb the mountain by solving problems about temperature, distances and time (see image 34). The mutual ownership is created by prompting both of the pupils to contribute to write the answers to the problems. To encourage all pupils to participate in the problem solving, the paper which is used to fill in the answers is designed so that the pupils can fill in every other answer. This is done to simulate the shift of placement of the keyboard in the app to promote the pupils to write an answer each, without excluding the other pupil to participate and engage in the content.

From the very start of the assignment in Mathy the pupils are asked to pick a quality that they want to practice during the session (see image 34). Further, they are asked to pick one that the group members together want to practice, thus setting a common

goal. All pupils are encouraged to contribute from the start as the character encourages cooperation, discussion and by addressing both pupils at all times. The open nature of the material should allow the pupils to engage with the content by discussing, writing, explaining and drawing. The paper template which is provided along with the digital prototype gives the pupils the opportunity to themselves divide who should fill in the results of each part of the assignment.

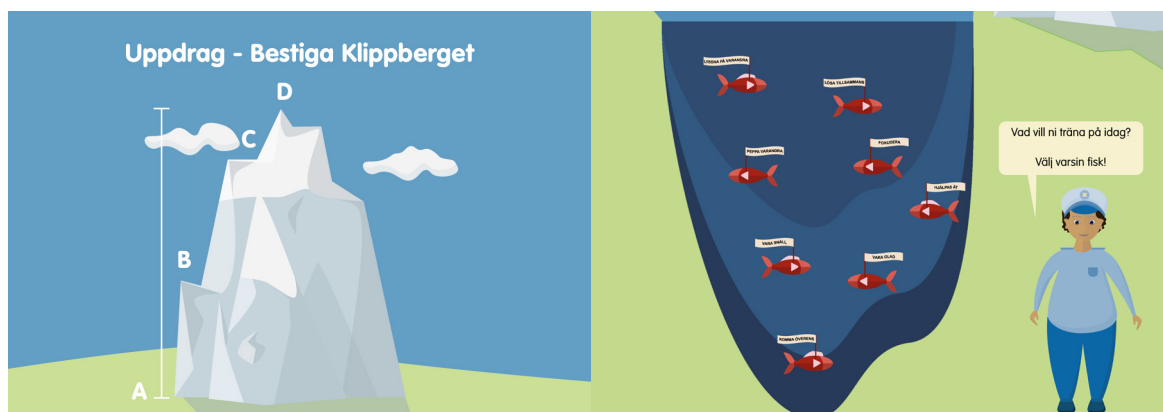


Image 34: The mountain that the llamas climb in Llamath (left) and the additive assignment in Mathy (right).

### 8.3.7 Communicate and Explain

Llamath will not limit the pupils' possibility to discuss, which can be done with videos or other formats that disable the pupils to discuss with each other. The tool will have two open-ended questions to promote discussions and argumentation.

As there are no simple answers to the questions in Mathy the pupils should discuss their thoughts and reflect on if their answers are realistic. The pupils are allowed to draw on the paper template which is provided.

### 8.3.8 Sharing

By encouraging the pupils to write the answers every other time in Llamath. The pupil with the higher knowledge is prompted to share their learning so that the other pupil is able to write the answer. The pupil will be able to share their progress with each other and discuss it since the llamas will visualise their progress by climbing further and further up the mountain.

As the assignment in Mathy requires the pupils to discuss they will hopefully also discuss and share their learning insights.

### 8.3.9 Constructive Feedback

In Llamath onstructive feedback is included by allowing the pupils to finish a whole assignment, consisting of multiple calculations, before informing them that something has gone wrong in the calculation. In the first step they will be prompted to try to find their error themselves.

If they still are incorrect they will be given instructions on which specific calculation that has gone wrong and they will be prompted to try to understand what went wrong. If they still fail to understand they will be given a short explanation.

Pupils are given positive feedback on effort throughout the assignment by the character Mathy and by their peers at the end of the assignment (see image 35). By providing the pupils with real life examples the pupils can reflect on whether their answers are reasonable and explain why or why not they are reasonable.



Image 35: The characters in Llamath (left) and Mathy (right) encouraging the pupils.

### 8.3.10 Encourage Reflection

There will not be multiple choice questions. The pupils need to fill in the answers themselves and the tool will with this strategy try to minimize the risk of guessing.

The character in Mathy emphasizes the importance of learning from failure and provides an example by making a mistake and learning from it.

## 8.4 Discussion & Implication

Below the implementation of guidelines and limitations of the concepts are discussed. The main differences between the concepts are explained under implications.

### 8.4.1 Discussion

The concepts are designed to visualise a section of the whole app. Designing several assignments and the teacher interface was not prioritised since the main focus was to evaluate the learner to learner collaboration. The most relevant guidelines were carefully selected by the authors with regard to feasibility in prototyping, learning mathematics and the definition of collaboration.

It was from the previous phases shown that individualisation was highly appreciated by the pupils. They took pride in their own creations and spent time styling avatars and creating backgrounds to their tablets. It would have been of interest to design a concept where the pupils could individualise their experience and at the same time learn mathematics. However, with the fidelity of the prototype it was difficult to implement this feature. In future a design it would be interesting to evaluate if and how individualisation could contribute to collaborative learning.

The focus of this thesis is to enable collaborative learning of mathematics and therefore the concepts have not mainly been created with respect to usability aspects. The concept aspired to be of a level where the usability would not interfere extensively with the evaluation of the concepts. By designing the concepts to include both digital slides and paper sheets the pupils have a larger amount of material available at all times. This will in turn mean that they have access to more visual support simultaneously. In future designs it would, therefore, be of interest to design the interface so that the pupils easily can access the visual support needed to solve the mathematical problems and to discuss. Further, the paper sheets were used to answer since the tools for digital prototyping did not allow the pupils to draw or type. For future design it is of interest to test how this could be implemented in a way that is not only easily used by the pupils, but also that encourages all pupils to be included.

#### **8.4.2 Implications**

Two concepts were developed and prototyped. The concepts differ in many ways and the main differences are how the questions are formulated in terms of openness and in what ways visual support for argumentation is included. The concepts were designed in this way so that the evaluation would provide a clear direction for the illustrative concept.

**Summative  
evaluation**

**Aim**

**Method  
&  
Procedure**

**Summative  
evaluation**

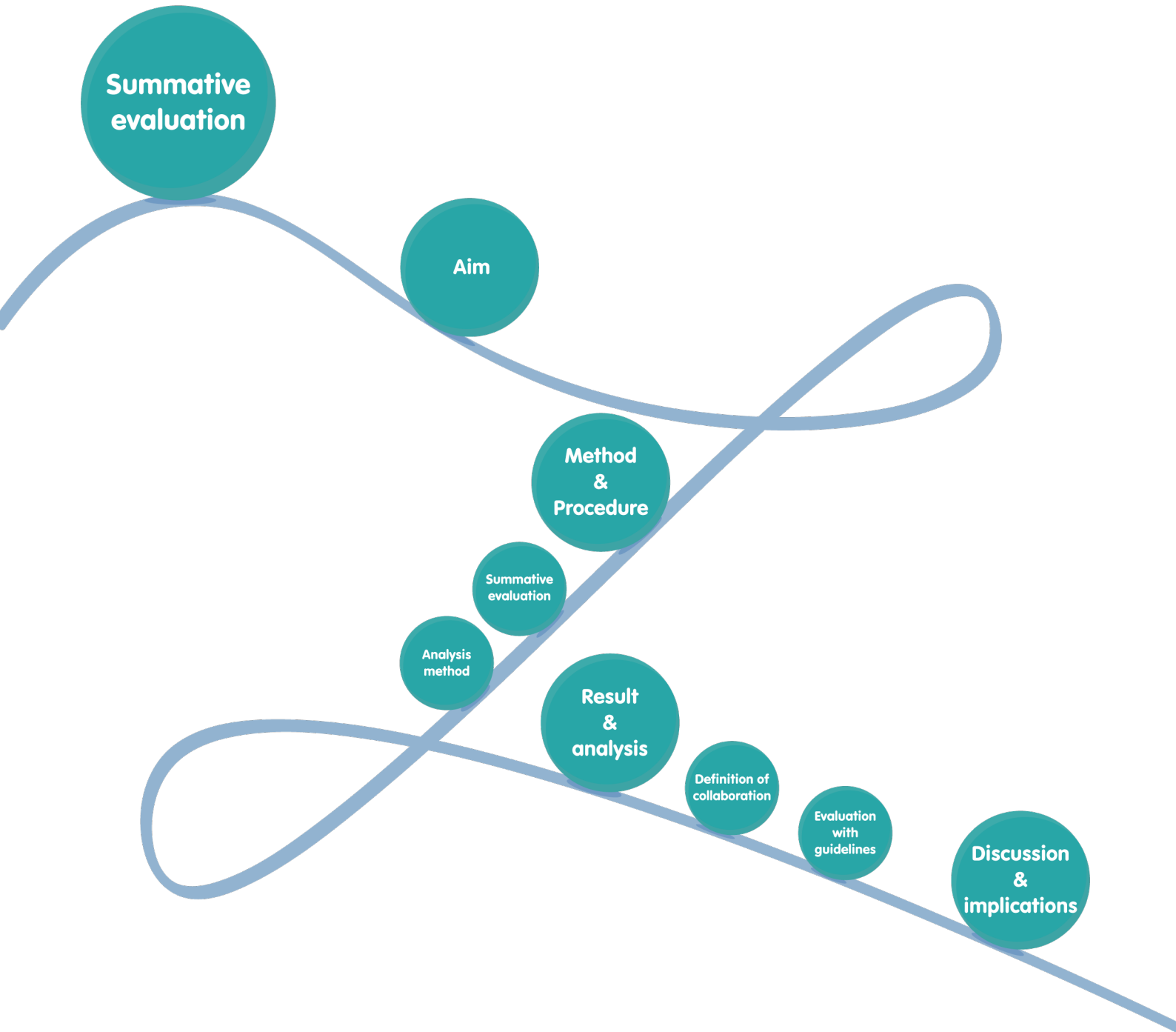
**Analysis  
method**

**Result  
&  
analysis**

**Definition of  
collaboration**

**Evaluation  
with  
guidelines**

**Discussion  
&  
implications**



# 9. Summative Evaluation of Initial Concepts

The purpose of the summative evaluation was to give the pupils an opportunity to give their opinion on the developed concepts and to evaluate the concepts in context. The concepts were compared to each other to evaluate how the guidelines were fulfilled in the best way. This was done by performing evaluations with two groups consisting of two pupils per concept. The results were categorised under each the relevant guideline and the concepts were compared to each other.

## 9.1 Aim

The aim of the evaluation was to test two concepts at an early stage to evaluate whether or not the guidelines can be implemented in these ways and to gather data that can be used to develop an illustrative concept.

## 9.2 Method & Procedure

The definition of collaborative learning was defined as: A situation in which two or more pupils with shared group purpose can exchange information and perspective to learn or attempt to learn something together. The summative evaluation was designed to test if the pupils work together in a manner that fulfills the definition of collaboration with these concepts. Due to the fact that the evaluations had to be implemented to fit the lesson time and average time that pupils conduct group work the evaluations were designed to take half an hour. Therefore, priorities had to be made that could be evaluated. The pupils were therefore only allowed to test one of the concepts and the pupils could not compare them to each other. Two concepts were made with three main parts; an initiating assignment, a main assignment, and a summarising part.

The evaluation was conducted in two schools during lesson time and the results were analysed and presented in comparison to the guidelines (see image 37).

### 9.2.1 Summative Evaluation

Each concept was evaluated with two groups of pupils consisting of two pupils from year one and three. The evaluations were summative as they were conducted to gather final feedback on the concepts. The evaluations were conducted during lesson time where groups that were selected by the teacher joined the authors in a separate room in the classroom (see image 36). This was to be able to test the concepts in a context which is as close to the real context as possible without interfering with the education.



Image 36: Setup of the evaluations at both schools.

The evaluations followed a structured evaluation plan (see appendix H) where the authors asked questions to the pupils at predefined times. The evaluation plan was created based on the guidelines and the definition of collaboration and consisted of categories such as discussion and explanation, visual support, and disagreement. A structure was set up for how the authors should handle incorrect answers and disagreements without progression between the pupils.

Pupils were instructed to discuss with each other if they had questions about the assignments but to ask the authors if they had questions about the functions of the concepts. The authors explained to the pupils that the evaluation was focused on evaluating the concepts and not the pupils' performance to create an atmosphere where the pupils felt comfortable to do the assignment and give feedback on the concepts. To decrease the impact of the authors presence during the evaluation one author explained the concept and asked questions while the other author was quiet and took notes.

The authors took photographs of the pupils while they were working on the assignments. The authors made sure that the pupils' faces were not visible so that all collected data remained anonymous.

The pupils that were not able to take part in the evaluation were still able to see the concept as the teachers were provided with printed booklets of the illustrations. In the final pages of the booklet the pupils were able to give opinions on the visuals of the concepts and write suggestions on what the concepts should be named (see appendix I). During the first evaluation the teacher incorporated the material in the lesson but not all pupils had time to look at both concepts. During the second evaluation the teacher did not have time to show the material to the pupils and it was therefore left at the school so that curious pupils could look through it at another time.



**Lake School**

Year two  4 Pupils



**Forest School**

Year three  4 Pupils

Image 37: Illustration of visited schools: The illustrations of children indicate group size

## 9.2.2 Analysis Method

The data was analysed by comparing the result from each evaluation to find patterns and differences. This result included for example, incorrect answers in terms of how many were made and corrected and how the pupils found the mistakes. Furthermore, the pupils' discussions were analysed by taking notes on their arguments and behaviour, such as pointing to the visual support. These insights were organised after the learning guidelines to clarify whether or not the guidelines had been successfully implemented. Quotes of what the pupils said were also organized within the guidelines to further clarify the pupils' perspectives.

The following factors were analysed:

Shared group meaning

- Did the pupils have a mutual understanding of the purpose of the assignment?

Disagreement

- Did the pupils discuss and come to an agreement?
- Did the pupils discuss without coming to an agreement?

Visual support

- Did the pupils refer to the visual support by either pointing or expressing with words?

Error

- Number of errors?
- Number of errors found and corrected by themselves?
- Number of errors found and corrected with one hint?
- Number of errors found and corrected when pointed out?
- Number of errors unable to correct without help?
- Did the pupils discuss errors? What did they say?

Inclusion

- Did both of the pupils write down the answers?
- Where both pupils included in the giving inputs or calculating?

Discussions

- When did the pupils use the visual support?
- How did the pupils use the visual support to discuss?

Interview

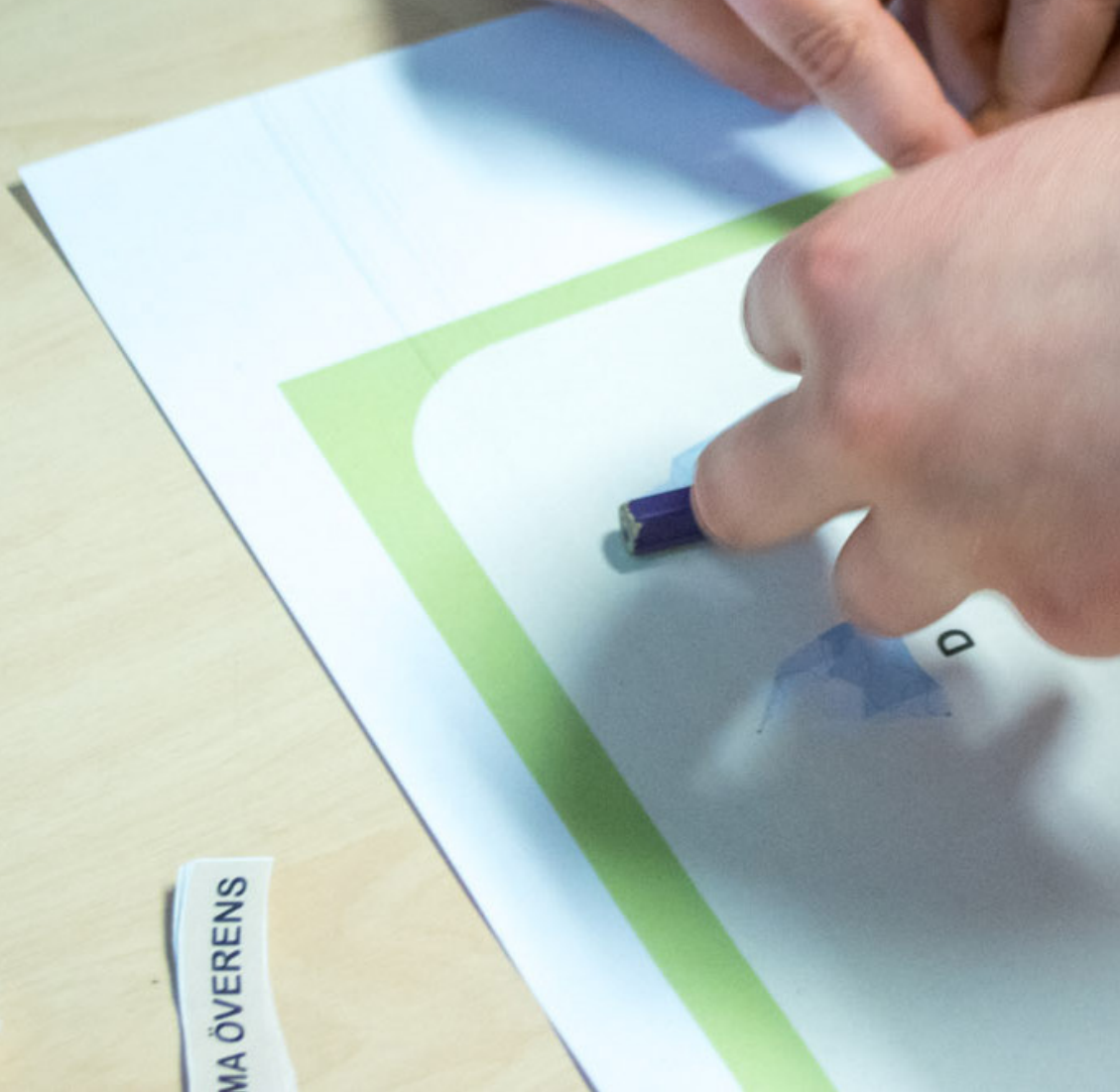
- What did the pupils say about the concepts?

Praise

- Did they praise each other spontaneously?
- How did they phrase the praise on the reward?

LYSSNA PÅ VARANDRA

MA ÖVERENS





**Pupils measuring and discussing the visual support.**

## 9.3 Result & Analysis

The initial concepts were evaluated with pupils to compare the design solutions. The definition of collaborative learning was defined as: A situation in which two or more pupils with shared group purpose can exchange information and perspective to learn or attempt to learn something together. This is analysed within the guidelines 9.3.8 The assignments should be designed to promote inclusion of all group members, 9.3.9 The tool should encourage the pupils to communicate with and explain to each other and 9.3.10 The tool should mediate and encourage sharing between pupils. These three guidelines were therefore considered to be the most important during the evaluation.

### 9.3.1 Lesson Time

Within this guideline the results were the same for both concepts. The concepts were adapted to the lesson time as the evaluations were planned to take 30 minutes per group.

During the evaluation the pupils were able to see how much of the assignment they had left to do as they had the answer sheet in front of them all the time. Therefore, when the concepts were evaluated in the first school and there was not enough time for them to finish the assignment it was clear that all questions had not been answered. However, none of the participants commented on not answering all the questions. When the concepts were evaluated in year one both groups finished the assignment within the allotted time.

### 9.3.2 Clear Instructions

In the tests of both concepts the pupils found it difficult to know when to change to the next slide and they would ask the authors for confirmation. Continuing, in Llamath the pupils sometimes struggled to find information as it was written in the heading of the assignment (see image 38). This is believed to be because the information was not as integrated into the square where the answers were written. When evaluating Mathy the pupils did not answer all the questions fully but had to be prompted by the authors to write or draw their explanations. This problem likely originates from the instruction that the pupils should explain was not clear enough.



Image 38: Pupils with answer sheet in front of them.

### 9.3.3 Eagerness to Learn

This guideline includes enabling pupils to celebrate progress. In none of the evaluations of the concepts the pupils were visibly celebrating their progress. However, the concepts included celebration as the pupils were awarded a reward at the end of the evaluation consisting of illustrations of a chocolate bar or a trophy.

The pupils did not appear to find the chocolate bar very exciting and one pupil commented on it and expressed that he would have preferred to write on normal paper (see image 39). When he realised that part of the chocolate bar could be golden he became more enthusiastic.

*“Why are we supposed to write specifically on chocolate bars?”  
- Pupil at Lake School*



Image 39: The pupil on the right was initially not so impressed with the chocolate illustration.

The groups who received the trophies responded varyingly. The first group with year three students did not express a lot of emotions while the first year students appeared to be excited by the prize.

During the evaluation of Llamath with year three the pupils were engaged in the characters by talking about them throughout the assignment. The last assignment where the llamas were placed on top of each other resulted in laughter. This could be considered to cross the line to entertainment, however they did reflect on this by posing questions relating to why they were standing as they did. The pupils in year one did not comment on the characters and did not seem to consider the llamas to be fun.

In the evaluation of Mathy with year one the pupils talked about how they found it nice that the character was so encouraging and didn't just tell them that they were wrong or had to do things over.

*"It was good that it said good job! It was nice that it did not tell us that we needed to redo that."*

*"It is nice that you don't have to hear that you made mistakes and so"*

*- Pupils at Lake School discussing Mathy*

When evaluating Mathy the pupils seemed motivated to correct their answers when provided with realistic examples and asked to reflect on whether their answers were plausible. They would change their answers even if they were within the accepted heightspan because they felt that it was unrealistic that a mountain would be as high as Mount Everest. The pupils also changed their answers even if it was not required by the assignment which only asked them to reflect on whether their answer was reasonable (see image 40).

*"Oh! It is not as high as ours."*

*- Pupils at Lake School reflecting on the accuracy of their answer in comparison to Kebnekaise*



Image 40: Pupil erasing an incorrect answer.

### **9.3.5 Educational Methods**

The calculations were performed internally in both year one and two. The pupils used the visual support when answering questions relating to time and temperature. Furthermore, they pointed to the material to explain to their group members where to find information or where to fill in. In the evaluation with year three the pupil also used the visual support to reflect and estimate on questions that were not posed to them yet. This was done by discussing how long it would take for the llamas to climb the whole mountain when they had climbed the first stage. They also reflected on how far they had come in fractions.

The answer sheet of Mathy was designed to have space for both writing and drawing and this was explained by the character Mathy in the beginning of the assignment. When the pupils struggled to write an explanation the authors reminded them that they were allowed to draw which they later gladly did (see image 41).

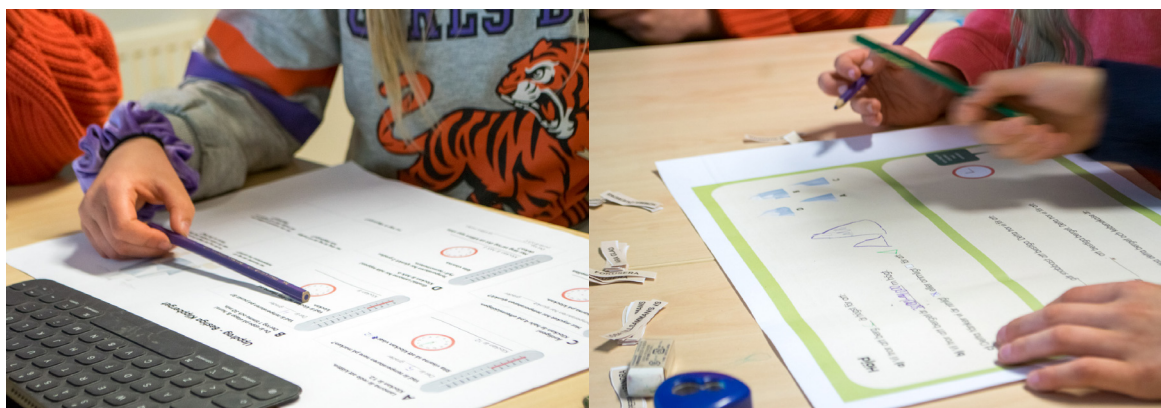


Image 41: Pupil pointing to the answer sheet of Llamath (left) and Pupils drawing the height difference on the answer sheet for Mathy (right).

Furthermore, the pupils used the visual support to compare heights of the mountains and pointed to the visual to emphasize which mountain they were talking about. They used their pens to measure the differences on the paper and based their answers on these measurements. Continuing, they used the available visual information such as steepness, trails and snow to discuss time and height. The pupils in year three looked for more visual support when they were to guess the height of the mountain. This was done by scrolling through the slides to see if they could find something with a height that they were familiar with, that they could relate the height of the mountain with.

### 9.3.6 Varying Prerequisites

In the evaluation of both of the concepts the teacher was asked to create the groups based on their knowledge about the pupils. They explained to the authors that they based their choice on having an equal amount of boys and girls, if they thought they would enjoy taking part in the evaluation and if they had finished enough of their school work.

The concepts were designed with the aim of the pupils to be able to work with what they recently practiced in the mathematics books. In the evaluation of Llamath with year three it was shown that one pupil struggled with how to place the pointers on the clock and the other pupil could then help by filling them out.

*"I'm not entirely sure if they are supposed to be there? (...) Do you know?" "Yes." "Comon!" "It is there, there is the long one because that is the whole..."*

*- Pupils discussing where the pointers of the clock are supposed to be*

In Mathy the pupils' prerequisites were less important as they could create a hypothesis about the answer and revise it when they were provided with more information. They were able to make use of previous knowledge that they had about mountains and distance and apply it to the assignment but it was not necessary.

*"50,000 meters perhaps?"  
"150 is like walking from our schoolyard to the car park"  
- Pupils discussing distances and heights*

### **9.3.7 Gain & Maintain Focus**

The pupils were focused during the whole evaluation, however, as described in one of the supporting guidelines the teacher presence affects the focus of the pupils. The authors were not only present during the evaluation, but did also take notes and were guiding when needed. It is therefore difficult to evaluate how well the concepts fulfilled this guideline.

The pupils in year three seemed confused with the initial videos that were intended to create focus by using rhythm. When evaluating Llamath the pupils, however, started to count down together. The pupils in year one did not seem as confused but it could not be determined if the video would help them to focus.

*"Okey, don't really know what the assignment is"  
- Pupil from Forest School*

### **9.3.8 Promote Inclusion**

In both concepts the pupils agreed on what they should do and had done during the session. Some of them explained by building on each other's sentences. This was considered to be an indication that the pupils had a common goal.

*"Figured out what they do to get up..."  
"...how long time it took..."  
"...how warm it was and what time it became"  
- Pupils in year one discussing what they had done during the evaluation*

In the concept Llamath the pupils took turns in writing down the answers. They did not switch between each assignment which was intended with the placement of the questions. They instead switched more often.

In Mathy all pupils could contribute from the start by selecting a fish. This was done by all pupils without any struggles. Whether this is an appropriate way of getting all pupils to contribute from the start in the long term is however difficult to predict. In this concept the pupils also took turns filling in the answer sheet but not to the same extent as in Llamath.

In year three one of the pupils wrote down most of the answers and did not include the other pupil in what they wrote. In year one, one pupil wrote most of the answers as well, however, they were both included. The pupil who did not write repeated their answer out loud in a slow pace so the other pupil could write (see image 42).

Towards the end of the evaluation of Mathy the pupils in both year one and three started to read out loud together. This was especially interesting as prior to that only one pupil had been reading. The last slides consisted of images and speech bubbles of the character climbing the mountain and commenting on the conditions.

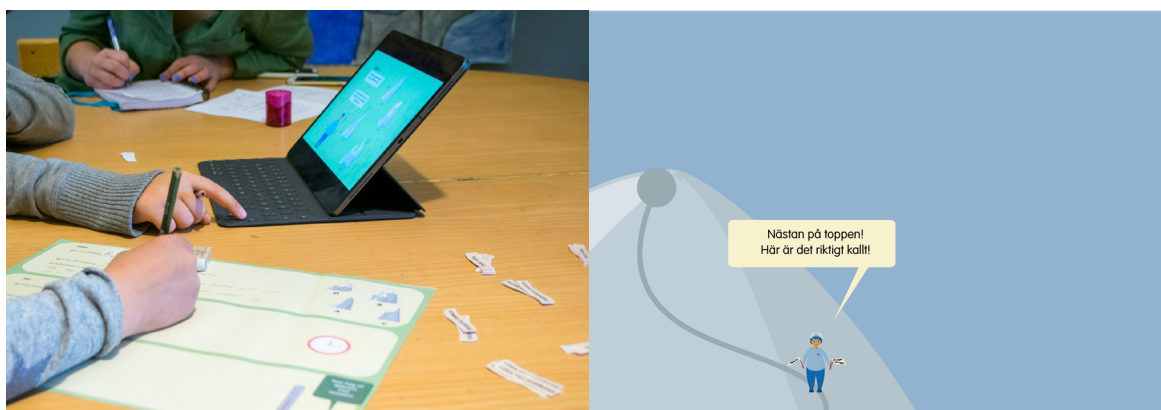


Image 42: One pupil has taken charge of writing without including the other pupil (left) and Mathy climbing the mountain and commenting on the temperature (right).

### 9.3.9 Communicate & Explain

In both concepts the pupils discussed how to write down the answers after they had come to an agreement. To avoid writing long sentences they together tried to shorten the answers.

The llama in Llamath prompted the pupils to explain how they calculated to each other. This did not work as intended since the pupils gave an explanation to the llama instead of each other. The explanation was not formulated as instructions on how to calculate but rather how they had gained their knowledge, which does not contribute to a deepened knowledge.

*"We had learned the clock in school and then we understand how to do it"*  
- Pupils in year one

The format of the questions of Maths encouraged the pupils to discuss with one another. This was also encouraged by the character. In the first phase of the questions the discussions were rather broad and once they were given more information their discussion was at a more detailed level.

The visuals of the mountain gave the pupils help to formulate arguments and discuss. This was done by pointing at the mountains and comparing them to each other. By using the visuals they were able to discuss factors relating to height and time by discussing the trails, snow.

*"I think B" "Because it is not as steep" "Easier than if it is totally straight"*

*-Pupils in year one comparing the trails on the mountains to decide which one would be fastest to climb*

After the assignment the pupils in year one returned to the paper to continue their discussion about the height of the mountains. The flexible format of the answers can be considered to enable the pupils to return and discuss the questions at any time.

### **9.3.10 Sharing**

Even though most of the questions in Llamath had a correct answer the pupils shared thoughts and perspectives with each other that were not directly connected to the posed questions. They shared their thoughts about why the llamas were to climb the mountain and reflected upon how long it would take for them to reach the top. The storyline and characters could therefore be considered to mediate the pupil to share insights between each other.

*"Do you know how far they have walked now? They walked for six hours, how fun"*

*"They are crazy. They are walking for six hours"*

*- Pupils in year three*

During evaluation of Mathy the pupils shared their knowledge to each other which was not only directed to mathematics or writing. They shared their perspectives by giving information about heights of mountains and distances.

### **9.3.11 Constructive Feedback**

When a mistake had been done by the pupils in Llamath, they were first given feedback to try to find the errors themselves. In year one they were unable to find the error and did not try to recalculate or discuss with each other in order to find it. When being presented with the error they were unable to understand how to correct it and needed assistance. In year three they seemed more inclined to find an error, but this resulted in one of them guessing on what could have gone wrong rather than reflecting or recalculating. After being presented with the error the other pupil could quickly see what was wrong and told the other pupil the correct answer.

In the final part of the Llamath assignment the pupils were given a paper with an illustrated chocolate bar where they were asked to finish the sentence I think you're good at... and give it to their group member. While the pupils appeared to find it easy to come up with something to write, none of the pupils kept the chocolate bar which can indicate that they were not very fond of it.

After the pupils had suggested a plausible answer in Mathy they were presented with information from real life, such as the height of Kebnekaise and Mount Everest. Both of the groups reflected on their previous answers and evaluated whether their answers were plausible or not. The feedback was presented in a manner where the pupils were presented with plausible answers without pointing out errors. This was considered to be a positive aspect of the concept according to the pupils in year one.

*"When we do like that they say we have to redo it if it is wrong. This was a lot better"*

*"They were saying good job, good job, good job"*

*- Pupils discussing the difference between the concept feedback and the classroom feedback*

The trophy the pupils were given at the end of the assignments was blank and the pupils were asked to write something nice to each other (see image 43). The pupils in year one struggled to come up with what to write whereas the pupils in year three were quick. Both of the groups asked if they could keep the trophies. The feedback from their fellow pupil was received without extensive signs of excitement.

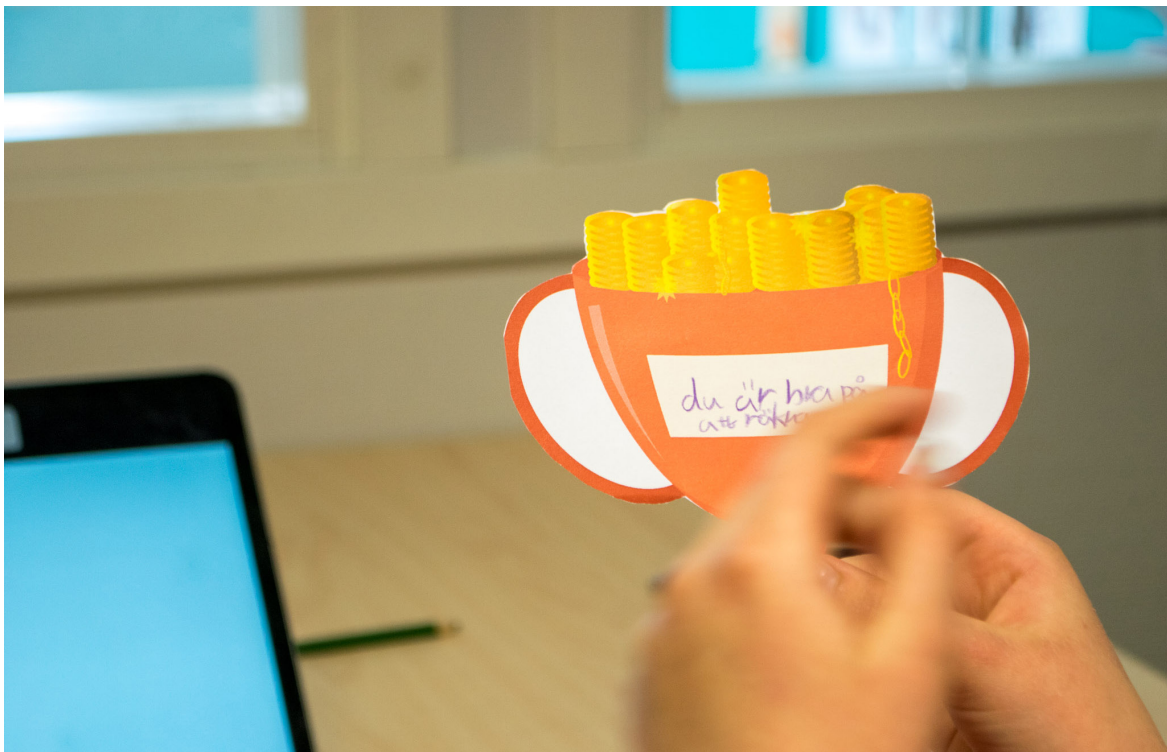


Image 43: Pupil holding reward that they have written on.

### **9.3.12 Encourage Reflection**

Llmath was designed without multiple choice questions and the pupils did therefore not guess the answers but calculated them instead. The concept included discussion questions where the pupils for example reflected on why the temperature had dropped and why some stages would take longer to climb than others. These did however not lead to discussions, but rather statements which they were quick to agree on. Both of the groups answered that one distance took longer to climb due to the steepness, this conclusion was not drawn by visual support and it could therefore be argued that more visual support could have helped the to discuss.

The formulations of the open ended questions required the pupils to form a hypothesis on answers they believed to be plausible. The intent was that they would make qualified guesses based on reflections and argumentation which were seen during the evaluation. When posed with the question about how high the mountain was the pupils in year three related their guesses to lengths that they were familiar with, such as the distance to the parking lot. The pupils in year one related it to previous knowledge such as the height of Mount Everest to try to draw conclusions.

*“How many meters high?” “It is cm high”  
“But if it would have been as high and in here. Like Mount Everest” “It is 8848 meters high”  
- Pupils at Lake School discussing the mountains*

### 9.3.13 Esthetical Guidelines

During the evaluations it seemed that the pupils did not understand the connection between the video, the world and assignments that followed them (see image 44). Only when it was explained to the last group who had questions about the parrot that they remembered from the formative evaluation it became more clear to them. After they had understood the connection they were very excited about the opportunities that came with it and started providing ideas on how it could be developed. Amongst their suggestions were a boat that had collided so that they would be stuck on the island and had to solve mathematical problems to escape the island.

When the pupils in year three tested Mathy one pupil thought that they could look at the world to compare the height of the llamas to the height of the mountain and thus figure out the total height. The authors were aware that the pupils are concerned with accurate proportions but had not foreseen this situation and it was evident that the llamas were clearly unproportionate to the mountain.

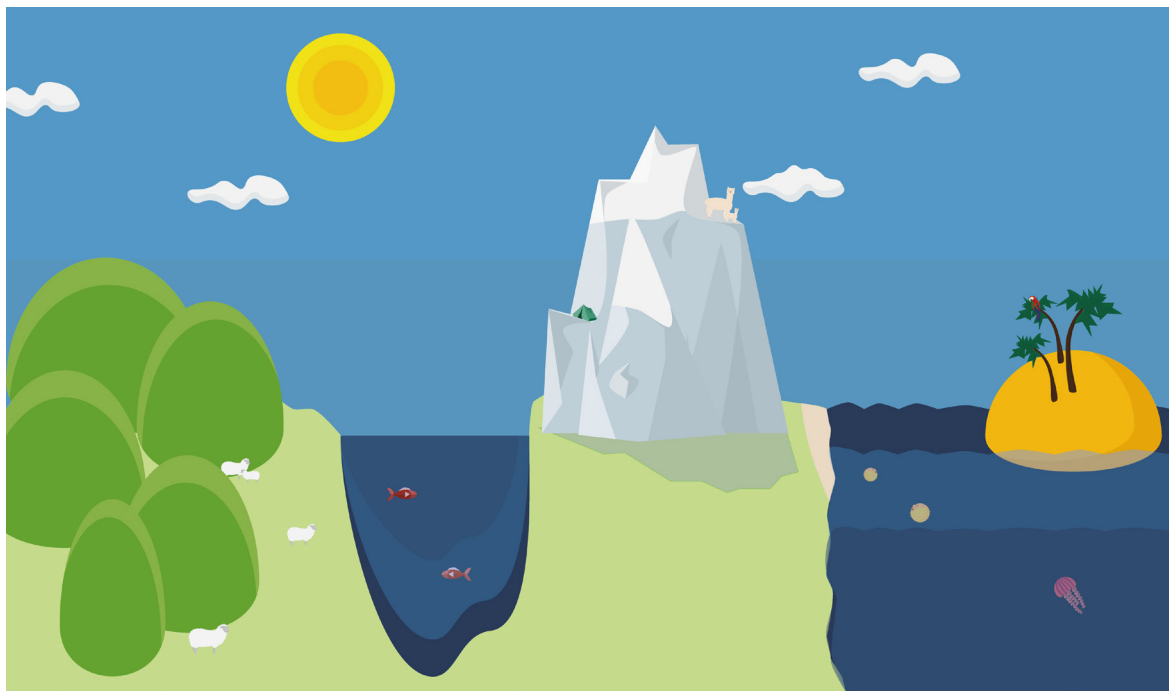


Image 44: Image of the landscape that the concepts were based on

Continuing, the pupils in year three who tested Llamath were doubtful about the llamas motives to climb the mountain. When discussing the amount of effort and time that it took the llamas to reach the top the pupils concluded that the llamas were crazy. While the pupils found this entertaining, it speaks to that the storyline was not clear enough for them.

The characters created varying responses with the pupils. The first group that tested Llamath seemed to be mostly impressed with the fact that the authors had created all the illustrations. One pupil in the second group who tested Llamath had some opinions on the design of the llamas stating that the legs were too thick and the ears were "too up."

*"They are not very good. The legs there, a little more thick. Ears more up. The legs are too thick."*  
- Pupils expressing their opinions about the llamas

The character and the fish in Mathy were designed to be fun features and while the pupils seemed to have nothing against them, they did not spontaneously comment on their appearance in a positive manner. It was therefore concluded that they did not find them interesting enough to comment on.

## **9.4 Discussion & Implications**

The evaluation process and its limitations are discussed below and the main results of the evaluation is summarised under implications.

### **9.4.1 Discussion**

Each concept was tested by two groups consisting of two pupils each. Due to the small amount of participants it was difficult to draw general conclusions of the gathered data. The individual differences are considered to affect the result to a high degree. The result can also be affected by the extent the class practice collaboration. The conclusions that have been drawn from this evaluation should therefore be investigated further to be able to provide a result that is general and not specific to the pupils involved in the evaluation.

Due to the authors presence the guideline regarding the focus could not be evaluated. Further, the authors could have affected the discussions and celebration. It was evident that some pupils in the beginning were nervous. Even though the authors stressed that the pupils themselves were not being evaluated the situation could have affected the pupils to act differently than in the real context. To not interfere with the education the tests were held in a nearby room. This exclusion from the classroom can also have affected the results as the pupils were not exposed to the same distractions as in the classroom context.

In the test in year one the teacher selected participants that had finished their assignments and were ahead of their fellow pupils. This was done in order to not interfere with the education, however this can have affected the outcome of the evaluation. The pupils would most likely belong to the pupils with higher levels of knowledge.

The concepts were new to the pupils and the long term usage could therefore not be tested. First impressions can give an indication to how well the design would function. It is however difficult to say how it would change over time, this is especially a concern regarding the pupils' esthetical preferences.

It was difficult to evaluate whether the pupils had a sense of having finished the assignment as they could see how much they had left on the paper sheet. This would not be the case

in a fully digital prototype as it could be designed so that the pupils cannot overview all the assignments at once. In the prototypes that were evaluated the pupils were given a reward at the end of the evaluation which can have created a sense of having finished the assignment.

### 9.4.2 Implications

#### Lesson Time

- The paper sheets allowed the pupils to see all available sub-assignments, which in turn indicated that they were not finished with the assignment.

#### Instructions

- The concept did not give clear indications to when the pupils should continue to the next question.
- The placement of the necessary information needed to answer a question was not placed in close relation to the question which led to confusion.
- The instructions of how the pupils should answer the question was inadequate which led to pupils missed answering questions.

#### Eagerness to learn

- The pupils did not celebrate their progress.
- To use a chocolate bar as an award was confusing to the pupils and they seem more appreciative towards the trophy.
- Pupils had a varying interest in the characters. One group discussed the llamas intensively whereas none of the groups commented on Mathy spontaneously.
- Appreciative towards being encouraged by the character in Mathy.
- The open-ended questions caused the pupil to correct their "errors" without being prompted.

#### Educational methods

- The pupils made use of the visual support to understand, explain and discuss.
- The visual support was used in other situations than intended to discuss questions that were not posed.
- The pupils needed to be reminded that they were allowed to draw instead of writing answers.
- The pupils looked for further visual support when creating hypothesis in concept two.

#### Prerequisites

- The questions with a correct answer led to the pupil with higher knowledge telling the pupil with a lower level of knowledge the correct answer.
- The open-ended questions in Mathy led to pupils making use of knowledge not only connected to the subject of mathematics.

#### Focus

- The pupils were focused during the whole evaluation but no conclusion can be drawn from this due to the authors' presence.
- One group started to count down together with the video.

### Inclusion

- Placement of the answer sheet in Llamath did not work as intended, instead the pupils switched filling in the answers more often.
- To which extent the pupils contributed to filling in the answers varied in all groups
- One pupil was excluded when filling in the answer during Mathy.
- The pupils agreed on what they were going to do and what they had done which could be considered them having a mutual purpose.
- Difficult to draw conclusions to whether it was positive to select what to practice at during the introduction.
- The pupils read out loud together in the final phase of Mathy.

### Communication and explanation

- The pupils did not explain how they had calculated when prompted.
- The open questions in Mathy mediated the pupils to discuss at a high level first and then in detail.
- The visual support helped the pupils to form arguments and discuss.
- The flexible format allowed the pupils to go back and discuss after they had finished.

### Sharing

- The llamas contributed to the pupils discussing with each other.
- The open questions in Mathy allowed the pupils to share knowledge about other subjects than mathematics.

### Feedback

- To let the pupils find their own errors led to guessing or them giving up.
- The pupils reflected on their hypothesis in Llamath and corrected their answer themselves.
- The pupils received the positive feedback from each other without any noticeable reactions.

### Reflection

- All of the pupils calculated or discussed prior to answering a question.

### Estehical

- The storyline was not described properly to the pupils.
- The wrong proportions between the llama and the mountain in the initiating screen could have led to faulty conclusions.
- The pupils did not mention the visuals in Mathy.

The most promising functions found in the initial concepts are summarised here. The visual support in Mathy aided the pupils in forming arguments and discussing with each other. Furthermore, providing the pupils with real examples caused them to reflect on the plausibility of their answers. In Llmath the visual support instead allowed the pupils to practice and explain more concrete mathematical problems that were more closely connected to the mathematics book. The characters in Llamath interested the pupils which was considered beneficial. It is however, important to ensure that the character provides the pupils with support for learning to ensure that they will not distract them from education. The character Mathy's encouragement was appreciated by the pupils.

Illustrative concept

Aim

Method  
&  
procedure

Illustrative concept

Explanation  
with  
guidelines

Discussion  
&  
implications

# 10. Illustrative Concept

The purpose of this chapter was to create an illustrative concept based on the insights gathered from the evaluation of the two concepts in the previous chapter. The designs that were evaluated to contribute to the highest level of collaboration were selected and together formed the illustrative concept. The guidelines that were excluded from the two concepts due to the limitations of the evaluation has been included in the illustrative concept to create a more holistic view. The concept was presented in the form of a strip with explanatory text that correlated to the guidelines

## 10.1 Aim

The aim of this chapter was to create a concept that enables pupils to learn together through a mediating, digital interface

## 10.2 Method & Procedure

The illustrative concept was created by further developing the positive aspects of the two concepts that were evaluated in chapter 9. The negative aspects of the concepts that were found during evaluation were replaced or redesigned. The guidelines that were not addressed in these concepts were ideated on through discussion between the authors.

### 10.3 Illustrative Concept: Macoo

Macoo will primarily be used by groups of two to enable all of the pupils to engage with the content at the same time. It will be part of a digital mathematics book where each chapter is summarised with the collaborative assignments in Macoo. The content will be based on the previous chapter, thus enabling repetition and a possibility to deepen the knowledge through discussion and reflection. Depending on how the mathematics book is designed, Macoo can be used either on a tablet or a computer.

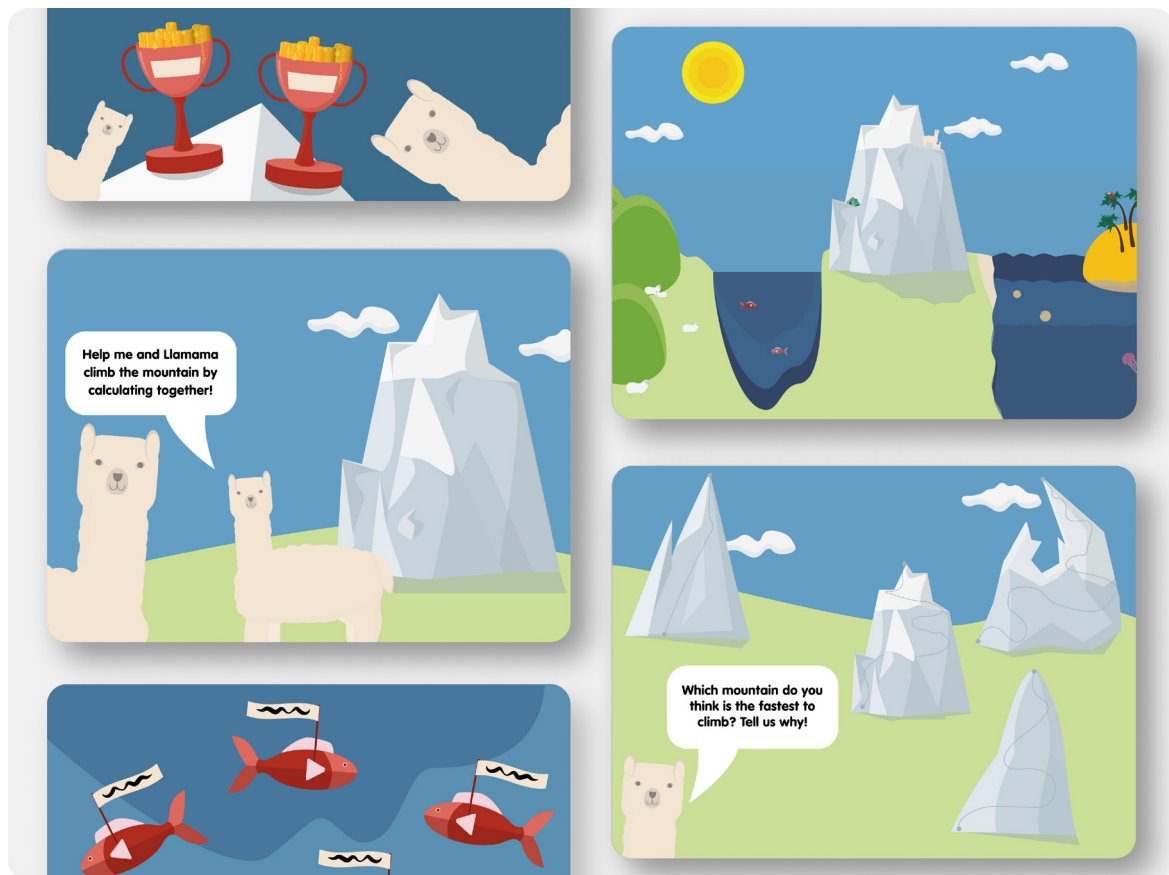


Image 45: Illustration of some of the screens in Macoo.

Macoo is built around a world, see image 45. The pupils will explore the parts of the world in different assignments. Each part of the world has different animals that present information that is relevant to the assignment. In the assignment that is presented in this thesis the pupils will visit the mountain and practice measurement, such as temperature, distances, and the clock.

### 10.3.1 Teacher

The tool should be designed to assist the teacher in their work and utilize their skills.

An interface is especially designed for the teachers so they can easily create groups, see the groups progress, and assign pupils with the assignment relating to the chapter in the mathematics book (see image 46). Since the collaborative assignments will be integrated in the mathematics book the individual progress can be easily accessed and utilized when creating groups.

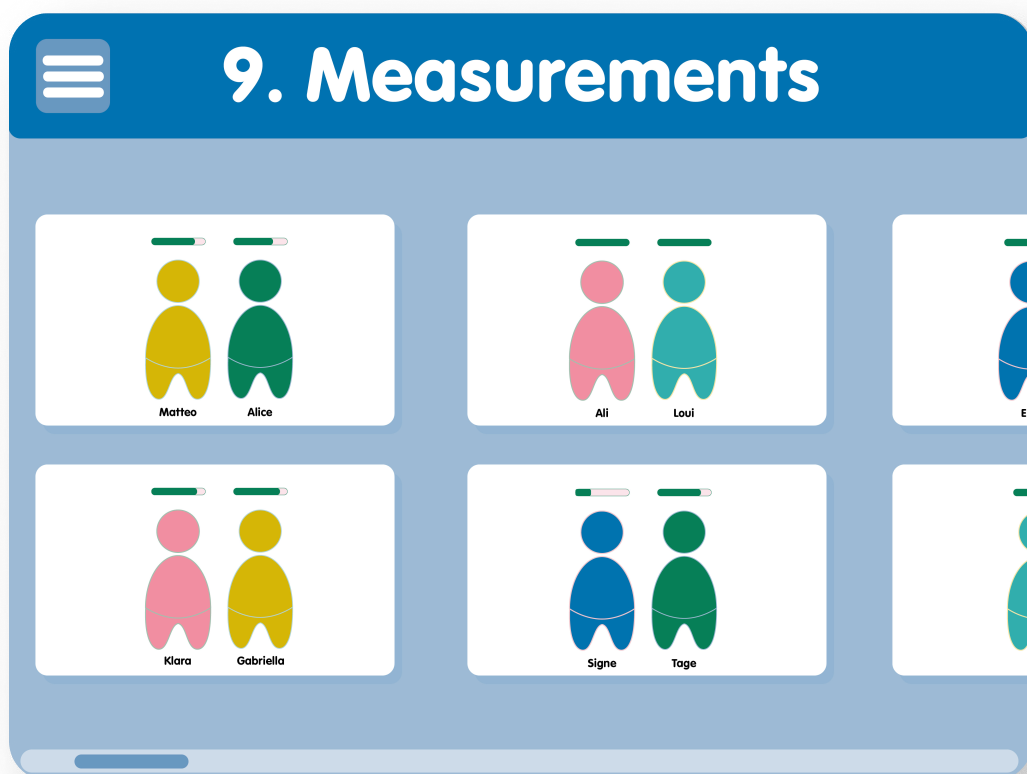


Image 46: Illustrative concept of teacher's interface.

### 10.3.2 Lesson Time

The tool should be adapted to the lesson time.

The assignments in Macoo are designed to take the pupils approximately 30 minutes to finish to fit the lesson set up. Due to the pupils' varying pace the assignments are divided into smaller sub-assignments to increase the pupils' sense of having made progress and finished parts (see image 47). All available sub-assignments will not be visible to the pupils simultaneously. To further increase this sensation the pupils will be rewarded in the same manner independent on how far they have come. The teacher will have the information about the groups progress and could allow them to finish at another time if desirable, if not the pupils will still feel as if they are finished. To allow change of group composition the assignments are independent of previous assignments.



Image 47: Macoo's assignments are divided into sub-assignments.

### 10.3.3 Clear Instructions

The tool should provide pupils and teachers with clear instructions.

The information needed for each assignment is placed in direct relation to the question to make the pupils more easily find them and understand (see image 48). To minimize the risk of pupils not understanding how or where to answer this will be indicated with for example a line. The of Macoo interface will give clear visual cues to indicate when they should move forward to the next sub-assignment.

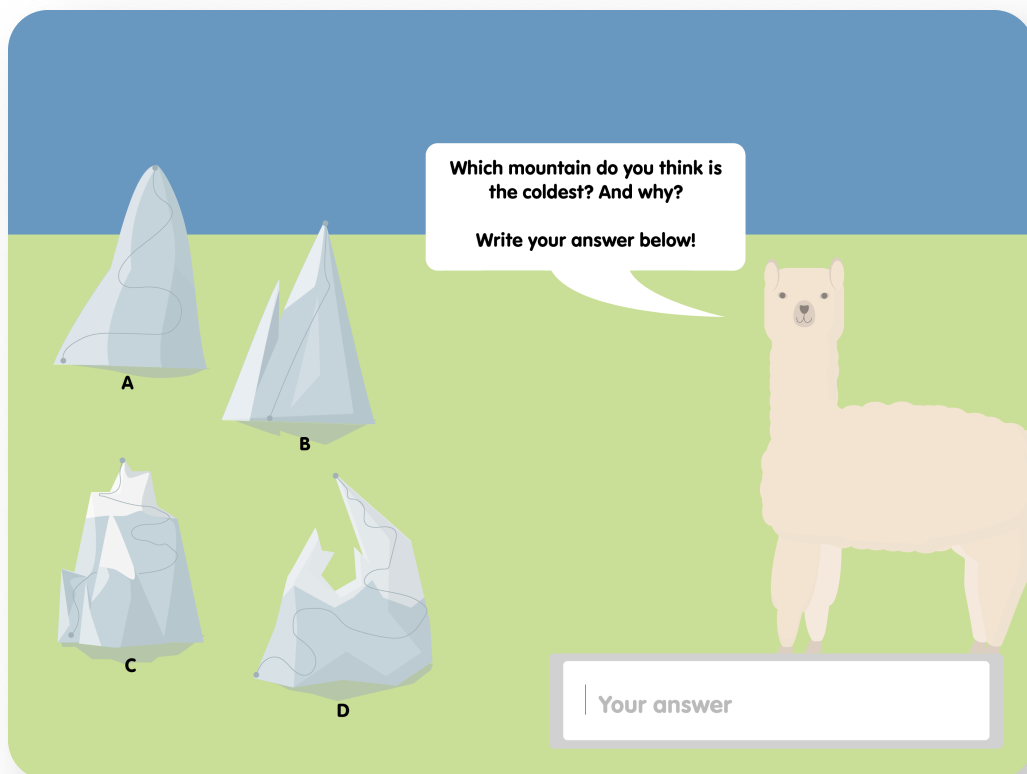


Image 48: The llama gives the pupils instructions.

### 10.3.4 Eagerness to Learn

The tool should maintain the pupils' eagerness to learn and their positive as well as curious attitude.

Macoo encourages the pupils to celebrate progress by including celebrations such as words of encouragement from characters and by including appealing rewards for progress (see image 49). The concept also allows the pupils to celebrate progress spontaneously on their own terms by emphasising their progress by visualising the characters progress. The open question motivates the pupils to reflect and correct their own answers by receiving examples relating to the question.

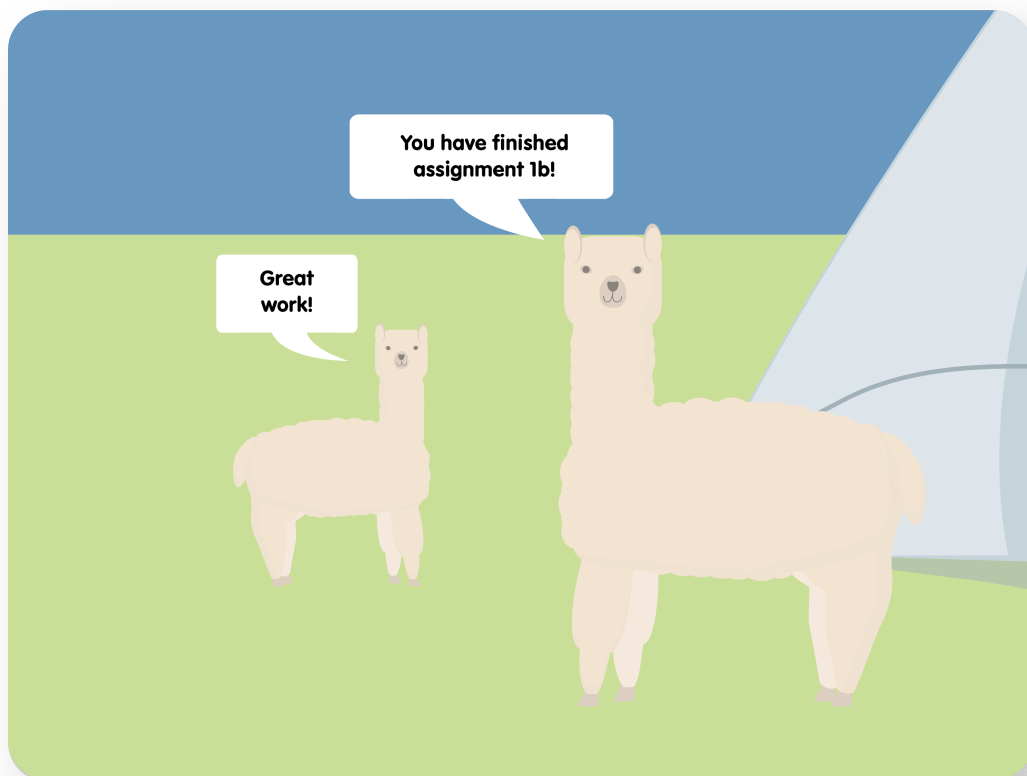


Image 49: The llamas encourage the pupils.

### 10.3.5 Educational Methods

The tool should encompass different educational methods and internalisation of knowledge.

The language in Macoo is adjusted to the school year it is used in for example by containing shorter sentences in year one and longer sentences in year two. All assignments are accompanied by visual support that further explains the assignment (see image 50). The visual support is designed to help the pupils understand the link between abstract and concrete mathematical problems. The questions allow the pupils to make use of their preferred learning technique but if the answer is incorrect several times the interface will advise the pupils on how to calculate the assignment. The close-ended questions are based on the content of the chapter, thus enabling repetition.

**How long did it take to climb?**

**Tips! Learn by looking at the clock step by step**

The clock is half past one \_\_\_\_\_ has passed

Image 50: An example of how the assignment is further explained in Macoo.

### 10.3.6 Varying Prerequisites

The tool should be flexible to fit pupils varying educational and social prerequisites.

By designing Macoo to complement each chapter in the mathematics book as a finishing part the concept ensures that all pupils have the prerequisites necessary to participate in a rewarding way. Furthermore, this enables the teacher to base the group division according to how the pupils performed in each chapter to ensure the groups have varying levels of knowledge. Continuing, by including open-ended questions the pupil with less knowledge about the specific subject can share their insights (see image 51).



Image 51: Open questions allow the pupils to participate on equal terms.

### 10.3.7 Gain & Maintain Focus

The tool should be designed to gain and maintain the pupils' focus.

As focus is an important factor in learning it is addressed in several manners within Macoo. This is done by including content that the pupils find interesting, which is further explained in the esthetical guidelines, and incorporating rhythm (see image 52).

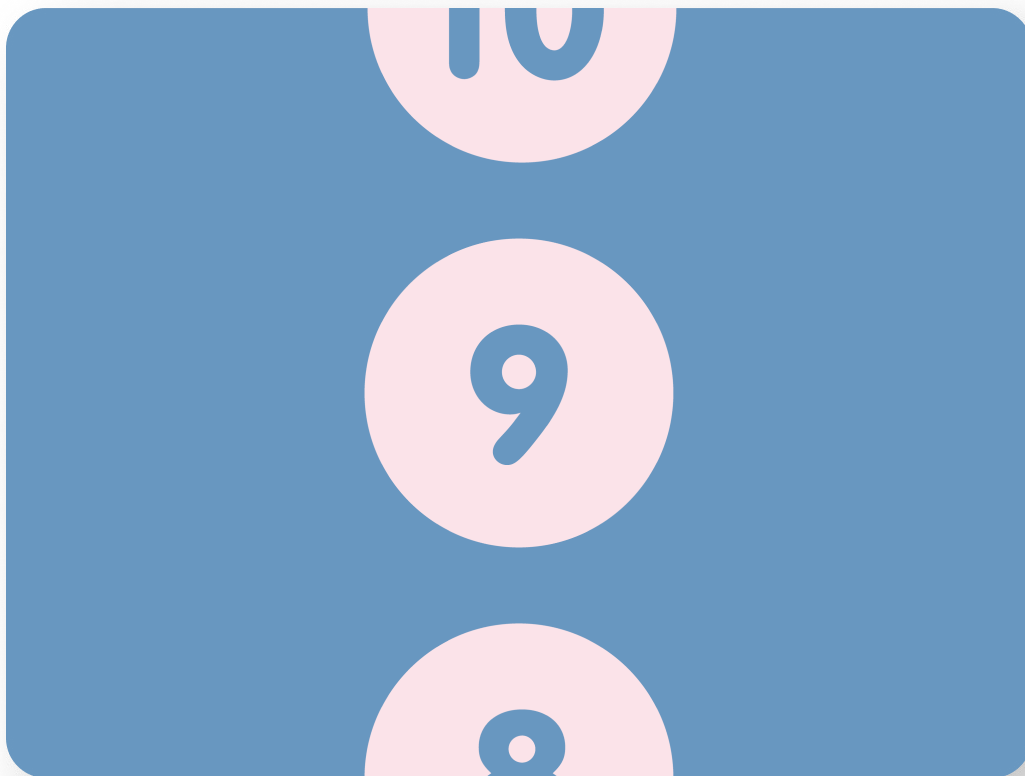


Image 52: A countdown in Macoo.

### 10.3.8 Promote Inclusion

The assignments should be designed to promote inclusion of all group members.

All pupils should feel and be included in Macoo. Therefore, it is emphasised in the instructions that the pupils should work together to answer the assignments. As the pupils need a common purpose to collaborate, the interface will provide one by clarifying the aim of the assignment. Furthermore, the pupils are able to choose a quality related to inclusion that they want to practice during the lesson (see image 53).

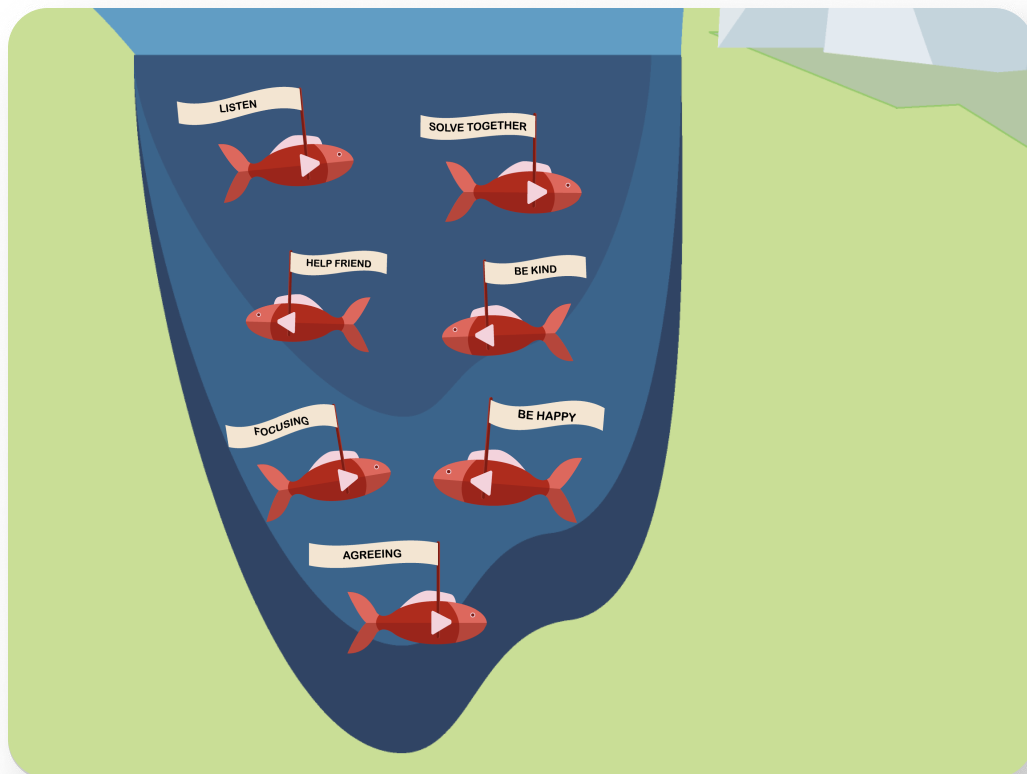


Image 53: The pupils can choose which qualities they want to practice..

### 10.3.9 Communicate & Explain

The tool should encourage the pupils to communicate with and explain to each other.

The questions in Macoo are a mix between questions with one correct answer and open-ended questions that encourage discussion. The open-ended questions are supported by visuals that help the pupils verbalise their thoughts and explain their point of view (see image 54). The visual support is of a somewhat ambiguous nature so that the pupils have to reflect on their answers thoroughly.



Image 54: The mountains remain visible so that the pupils can discuss them.

Continuing, the close-ended questions are also supported visually so that the pupils with a high level of knowledge can explain to pupils with a lower level of knowledge. The support that is relevant to the assignment is available to the pupils at all times as discussion can arise at any point of working on the assignment. Finally, pupils are able to draw answers or explanations on the digital interface as some pupils struggle to write long sentences.

### 10.3.10 Sharing

The tool should mediate and encourage sharing between pupils.

As the pupils enjoy sharing and as exchanging information and perspective are important factors in collaboration Macoo mediates sharing. This is done by including topics in which the pupils easily can share knowledge from their everyday life such as distances they are familiar with. Furthermore, by including open-ended questions the pupils are able to come up with a variety of answers that they can share and compare with each other. In the end of the lesson pupils will be given a digital reward that specifies what they have practiced today (see image 55). These awards are stored digitally and can be used as a way for the pupils to discuss progress.



Image 55: The pupils receive encouraging awards.

### 10.3.11 Constructive Feedback

The tool should provide the pupils with constructive feedback on effort and performance.

Macoo gives encouraging feedback on the pupils' efforts through the characters. When the pupils write incorrect answers the interface will indicate that where the mistake is with a small delay (see image 56). This allows the pupils some time to find the mistake themselves before they receive feedback. If an answer is incorrect several times the interface will support the pupils in their calculations through a step by step explanatory animation.

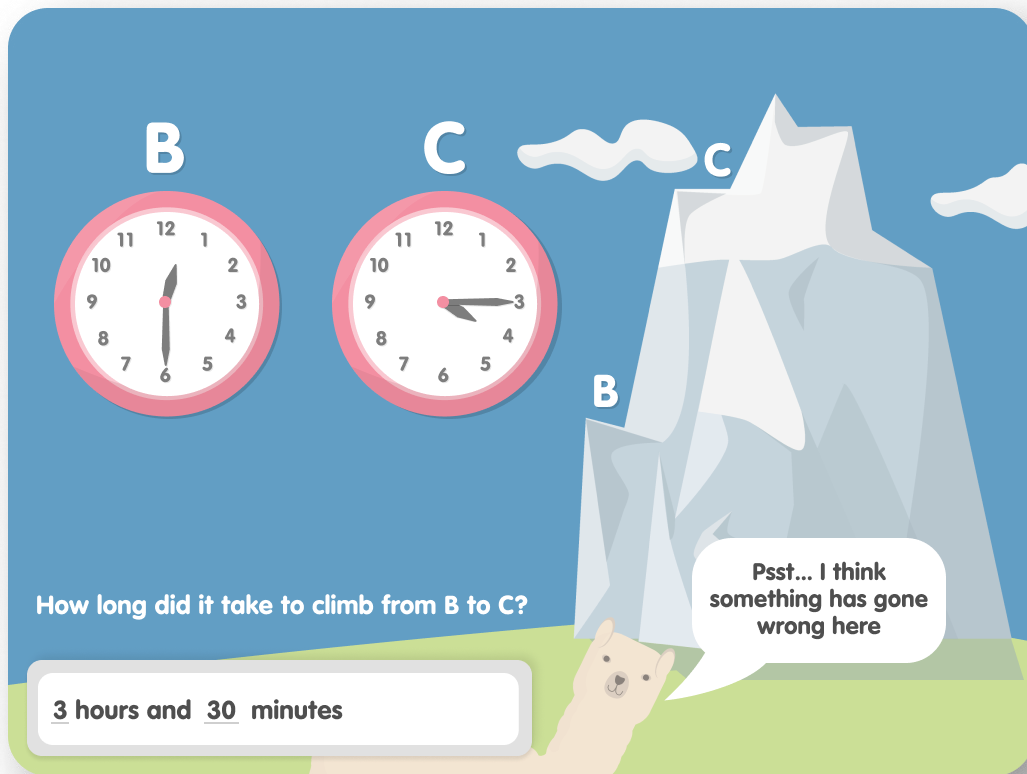


Image 56: The llama provides the pupil with constructive feedback.

### 10.3.12 Encourage Reflection

The tool should encourage reflection.

The characters within the concept will explain that failure is an important factor in learning and provide an example by making mistakes and learning from them. All assignments within the concept will require that the pupils write or draw their answer, which encourages the pupils to reflect on their answer and discourages guessing. As the open-ended questions will have several correct answers the pupils can reflect on why there are several correct answers and if one is more correct than the others (see image 57).

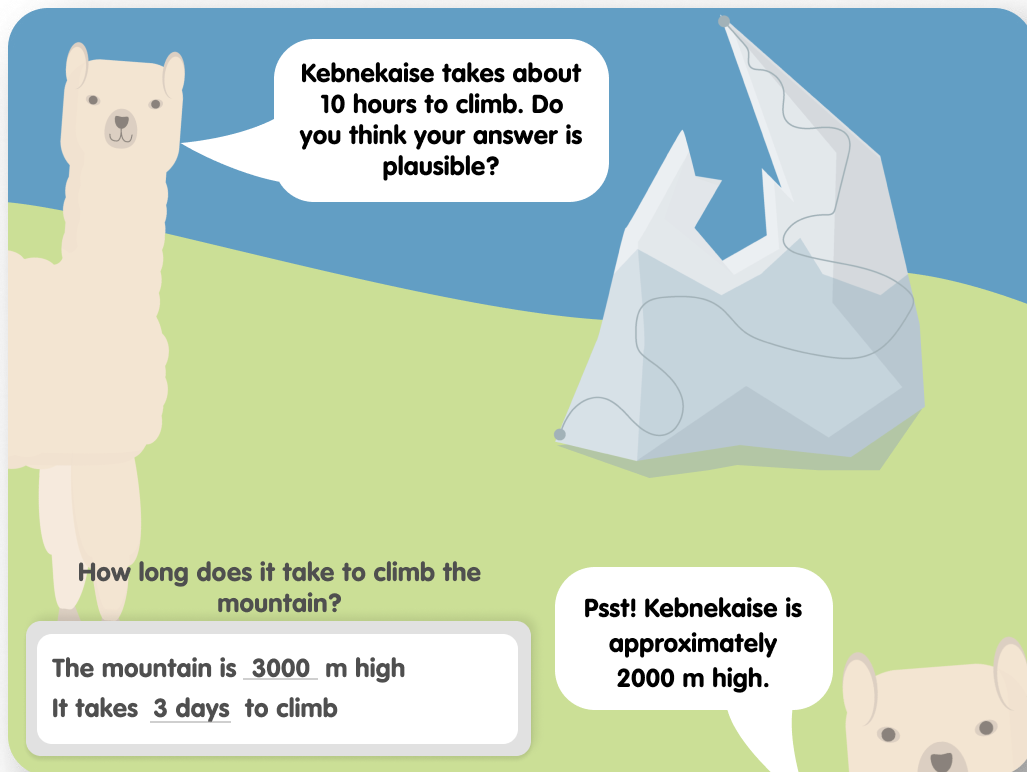


Image 57: The pupils can reflect on their answers by comparing them to real examples.

### 10.3.13 Esthetical

The visual aspect of Macoo is founded on the landscape which was included in both previous concepts. This landscape is colourful and realistic in its proportions and shapes but still playful. The characters and other objects are also proportionate in relation to each other. This is important because visuals should fill a supportive function and the proportions can help the pupils to discuss and make hypotheses based on them. All characters within the concept will be based on animals that fit into the landscape.

In the beginning of the collaborative assignment the pupils will be given an introduction to the whole world and the story behind the assignments. In the beginning of each session a short recap will be given that will give the pupils a reminder of what they have practiced earlier and further create a storyline interests the pupils.

Macoo enables the pupils to edit content as they are able to change the colours of the rewards that they are given when having finished an assignment. They are able to change colour and add patterns to the trophies. As the reward is given at the end of the assignment, editing its appearance does not distract from learning.

## **10.4 Discussion & Implications**

Implementation of the concept and creation of an interface for teachers are discussed below. Further, the most important factors of the concept are summarised under implications.

### **10.4.1 Discussion**

The concept, Macoo, presented above is based on insights gathered throughout this thesis. However, Macoo has not been prototyped or evaluated by pupils. Therefore, it is difficult to predict if it can be implemented successfully.

Continuing, Macoo includes an interface that is especially designed for the teachers. It is considered beyond the scope of this thesis to research what such an interface should contain in detail. The needs behind the features that are described in the concept have been expressed by teachers to be important to their work.

### **10.4.2 Implications**

The most important factors of the illustrative concept, Macoo, are summarised below.

Teacher

- The teacher assign the pupils with the correct assignment through their interface.
- The teacher interface allows the teacher to see both individual and group progress.
- The interface allows the teacher to create groups based on prerequisites.

Lesson time

- The assignments are designed to take around 30 minutes to finish.
- The assignments have sub-assignment i.e., 1a, 1b, etc.
- Independent assignments allow for group change.

Clear Instructions

- All information should be easily overviewed.
- The visual cues will indicate how the pupils should fill in the answers, for example lines that indicate writing.
- The visual cues indicate when the pupils should move on to the next sub-assignment.

### Eagerness to Learn

- The characters visualise the pupils progress.
- The characters encourage the pupils throughout the assignment and celebrate their progress.
- The pupils receive rewards when progressing.

### Educational Methods

- The language is adjusted to the school year the concept is used in.
- The visual support includes clear clues that clarify the assignment.
- The visual support clarifies the link between abstract and concrete mathematical problems.
- The interface allows the pupils to try different learning techniques but provides advice when answers are incorrect.
- Repetition is enabled through close-ended questions.

### Varying Prerequisites

- Macoo includes a mix of closed questions that have a correct or incorrect answer and open-ended questions that allow the pupils to discuss.
- The open ended questions does not require an extensive previous knowledge on the subject but instead allow the pupil to create a hypothesis that they in a later stage can compare with realistic examples.
- The open-ended questions allows pupils of varying knowledge levels to collaborate on the same assignment and contribute with the knowledge they possess.

### Gain & Maintain Focus

- The content is aligned with what the pupils find interesting, for example many pupils empathise with animals. They are therefore included as characters that present the assignments.
- Macoo includes elements of rhythm such as countdowns.

### Promote Inclusion

- The instructions encourage all pupils to participate.
- Macoo provides the pupils with a common purpose by introducing the aim of the assignment such as; practicing distances, collaborate and helping the characters to achieve their goal.
- The pupils make an active choice to include all members by selecting what to practice during the assignment such as; listen to each other or be kind.

### Communicate & Explain

- Mix of closed and open questions.
- Open questions are supported by visuals.
- Keeping visual support available at all times.
- Giving the pupils space to draw if they want to explain something that is hard to write.

### Sharing

- Pupils can contribute with knowledge from everyday life.
- The variety of possible answers encourage discussion between groups.
- Rewards that symbolise progress.

#### Constructive Feedback

- The characters will provide encouraging feedback on effort.
- Incorrect answers will be indicated to pupils with a short delay.
- The interface will help the pupils through explanatory animations.

#### Encourage Reflection

- The pupils will be encouraged to reflect on failure by the characters.
- All assignments require writing or drawing the answer.
- The open-ended questions encourage pupils to reflect on possible answers.

#### Esthetical

- Macoo's visual content is colourful with realistic proportions.
- The visual content is supported by a holistic storyline.
- The pupils can edit the colour and pattern on rewards they are given.



**General  
discussion**

**Process**

**The  
illustrative  
concept**

**Future  
work**

# 11. General Discussion

In this chapter the process and illustrative concept is discussed and recommendations for future development are presented.

## 11.1 Process

The close integration of the pupils and the teachers has been vital in the realisation of this thesis. There is a risk that the teachers that allowed the authors to visit and participate in their lessons are not representative to the schools in Sweden. Which in turn can affect how representative the classes are. In some of the schools the teachers already worked with incorporating collaboration into the education. In the participatory session and the evaluations, the pupils seemed to be more comfortable with the collaboration in some schools. This is believed to be dependent on how much the pupils had collaborated before.

The process presented in this thesis is focused on gathering data in an iterative manner and based on that data an illustrative concept has been designed. It would have been possible to collect less data and instead create more explorative concepts. However, it is the authors' belief that by basing the concept creation on the previous research it has been possible to discover and incorporate more factors that improve learning. As shown in the research there are many aspects that influence the pupils' ability to learn collaboratively. By reducing the collection of data and instead focusing on creating a larger number of concepts, there is a risk that aspects would not have been detected.

Due to the GDPR no recordings were done of the pupils and all data had to be registered by taking notes and sketching. This can have affected the accuracy of the gathered data. To minimize the risk of incorrections the notes were compared with the other author's notes.

The pupils did not have an opportunity to exclude themselves from the observations or the sessions due to the mandatory school system. The ethical aspect of performing user studies without it being fully voluntary could be considered problematic. The authors were taking extra precautions to make sure that all pupils were feeling comfortable during the user studies, workshops and evaluations. The pupils were not obliged to answer questions if they were unwilling and not prompted if they showed signs of reluctance. The teachers had also prepared the pupils in advance and the interviews and evaluations that were considered to be the most personal were voluntary.

It was from the beginning the authors' ambition that the collaborative aspect should be reflected in not only the design but also the process. Therefore, it was of great importance to involve the pupils throughout the whole design process. It became evident that most pupils were eager and curious to contribute with their ideas. The aim of the authors was to take inspiration from the pupils to create a design which they are interested in and could enjoy using. As is mentioned in the discussion in chapter 5, the authors have had to interpret the pupils and draw general conclusions from many individuals' preferences. When interpreting the pupils' work, behaviour, and words there is a risk of misinterpretation. This is always the case with user studies, but the risk appears to

be larger with children as they have difficulties expressing their needs. However, the pupils that have been involved in this thesis have been very frank in their criticism. The authors have tried to reflect the pupils' inspiring thoughts and curious minds in the illustrative concept, but as it has not been shown to any pupils it is hard to say if it has been successful.

During the whole process it has been of great importance to adapt the methods used to fit the pupils of the represented age groups. This was done by following the guidelines presented in literature and also by keeping the methods semi-structured to ensure that everything was enjoyable for the pupils to participate in. While this has been crucial for conducting these types of user studies, it has also forced the authors to be mindful about the balance of having a research approach and a child-friendly approach. The methods presented in the report are, according to the authors, well balanced. However, during the evaluations, attempts were made to include pupils who could not participate in the evaluations. These assignments were excluded from the results and are presented in the appendix as the data didn't meet the desired standards.

The process has been iterative, and the result of each analysis has been evaluated again in the following phase. This has allowed the authors to both test and build on knowledge from the previous phase. Especially the results from the first user studies in context have been analysed in an iterative manner as the vast amount of data was difficult to present in a reviewable and productive manner. The iterative evaluation of the results has increased the quality of the results and is hopefully reflected in the illustrative concept.

## **11.2 The Illustrative Concept**

The importance of language when learning mathematics has been stressed and acknowledged by both teachers and in the literature. When using a digital tool there is a risk that the pupils will not have the same opportunity to practice their writing skills. One of the key design features of this digital interface is however to stimulate discussions and argumentations which is another aspect of practicing a language. The use of a digital tool to learn mathematics can also enable pupils with motorical difficulties to participate in a more equal manner and their learning of mathematics will not be inhibited by their low writing skills.

The authors are convinced that for a digital interface for learning mathematics collaboratively to be successful, all the presented guidelines are important. When comparing the guidelines and the illustrative concept to the apps observed in the schools, the main difference is the collaborative aspect. With Macoo, the pupils will be given the opportunity to collaborate with each other and will be given support by the interface to do so. When focusing especially on the collaborative aspects it is most important that the concept responds to the guidelines regarding communicating and explaining, promoting inclusion, and encouraging reflection. These guidelines are imperative to fulfil the definition of collaborative learning, as it includes exchanging information and perspectives. To aid the pupils in fulfilling the definition, extra focus should be put on the visual support. It was found that the pupils could more easily form arguments, discuss, and explain to each other when presented with relevant visual support.

It was of importance to design an interface that did not encourage negative comparison or created new opportunities for exclusion. The aspect of including all pupils has been a priority throughout the whole process and design choices have been made to enable this. Without evaluation over a longer time period in the classroom context it is not possible to determine if this has been successful. However, the following factors in Macoo are believed to enhance inclusion and therefore minimize negative comparison; additive assignments, select quality to practice regarding inclusion, group size of two, and a variation of closed and open assignment. These factors have not been observed in the apps used in school, therefore, Macoo will hopefully not only minimize the risk of new opportunities for exclusion, but work for inclusion

As with all user studies it was important to study pupils in their context. It quickly became evident to the authors that the context greatly affected the pupils' ability to learn. Continuing, pupils are also responsible for how well their fellow pupils can learn as their behaviour in the classroom can affect the entire class. This becomes even more significant when it comes to collaborative learning, since the pupils learn or attempt to learn together. To further investigate how the illustrative concept relates to these factors, the authors recommend that the illustrative concept is tested in a classroom by a whole class.

During this thesis it has not been possible to determine if any of the concepts have improved the learning. The final concept is based on insights from the user studies and theory from the frame of reference on how to deepen learning. However, long term studies are needed to determine if and how the concepts provide educational benefits.

### **11.3 Future Work**

The authors have designed the level of difficulty of the assignments by consulting the mathematical books and teachers. However, they are well aware that they do not possess the education nor the experience to create mathematical assignments that exactly respond to the year. To be able to fulfill the guideline to follow the Swedish curriculum it is of importance that the assignments are created by, or together with, an expert within this area.

The main focus of this thesis has been on collaborative learning. Further studies are needed on usability, assignments, and storyline. The guidelines and illustrative concept can serve as a basis for these studies. Continuing, there is a need to research how to develop the concept into a fully functioning digital interface.

The primary users of this thesis were the pupils and therefore the teacher's perspective has not been researched or designed to the same extent. The teacher's perspective is however considered to be vital when designing the interface. Many teachers can decide whether a product will be used in their class or not. Further, the teacher is not only affected by the interface they themselves use, but also by the one used by the pupils. If the pupils have questions about the interface's functions or assignments the teachers should be able to handle these with ease. It is therefore of interest to further investigate how the teacher interface could be designed to meet their needs and wishes.

Prerequisites in form of knowledge and social factors have been taken into account during the design of the guidelines and the concepts. However, no research has been done with regards to pupils with special needs such as neuropsychiatric disabilities or physical disabilities. All pupils should receive an equivalent education that is adapted to fit their needs. For the design to fulfill this criterion it would have to be evaluated with respect to pupils with special needs of different kinds.



## 12. Conclusion

There are many factors that together create a good foundation for learning mathematics. Some of these are as follows; understanding the link between abstract and concrete, everyday life connection, visual support, and discussion. The teachers' important role cannot be emphasized enough and educational tools should be designed to aid the teacher, not to replace them.

The literature study showed that learner to learner collaboration has many positive effects on learning outcomes. Through the user studies it became clear that schools work with collaboration to a varying extent where some actively and strategically implement it in the lessons. Others worked generally with group assignments that included collaborative elements.

Collaborative learning has been defined as follows; A situation in which two or more pupils with shared purpose can exchange information and perspective to learn or attempt to learn something together.

A set of twelve educational guidelines and nine esthetical guidelines have been written to provide a base for how a digital interface can be designed to account for mathematical education principles and enhance collaborative learning in a primary classroom environment. Additionally, an illustrative concept has been designed to give an example of how these guidelines can be implemented.

The illustrative concept is designed to create group work that fulfills the chosen definition of collaborative learning. This is, in turn, what separates it from the tools that have been seen during the user studies. It is designed to enable and encourage discussion, explanation, and argumentation which allows the pupils to exchange information and perspective. It provides the pupils with a common purpose that clarifies to them why they are doing the assignments. Finally, it encompasses both repetition of knowledge and deeper learning as the pupils build on each others' knowledge.



**Conclusion**

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# Appendix

- A. Checklist for Observation
- B. Interview Pupils
- C. Interview Teacher
- D. Interview Experts
- E. Script for Participatory Sessions
- F. Script for Formative Evaluation
- G. Activity System Model
- H. Script for Summative Evaluation
- I. Methods for Inclusion of Pupils Who Could Not Participate

# A. Checklist for Observation

## Innan

Fotografera miljöer

Vad för böcker de använder

Upplägg för dagen - schema

Kvantitativt

Tid - lektion/upplägg: lärarlett, individuellt eller samarbete

Hur många i klassen

Hur är miljön

Foton på miljön utan barn

Möblering. Låst/fritt/individuellt/grupp

Vad finns runt omkring i lektionssalen, bilder/verktyg?

Vilka digitala verktyg finns?

## Under

### Mattektion

Upplägg på en mattektion. Hur lång är en mattektion? Individuell tid, grupptid,

Vad lär de sig? Exempel på mattetal?

Hur lär läraren ut under "föreläsning"?

Konversationer med varandra

Räcker de upp handen/frågar de bordsgrannen

Kan vi hitta roller (nån som hjälper andra/nån som vill vara själv)

Hjälper de varandra över bordsgränserna?

Vad finns det för fysiska hjälpmedel, hur används de?

Vad verkar de tycka är roligt?

Hur betar de sig när något är svårt?

Vad tycker barnen om matte?

### Lektion

Hur länge fokuserar de?

Vad verkar de tycka är roligt?

Hur betar de sig när något är svårt?

Är alla med under alla delar av lektionen?

### Samarbete

"Tvingat" samarbete, hur ser det ut? Vid vilka tillfällen, i vilka ämnen?

Vid "tvingat" samarbete, hur ser gruppdynamiken ut? Är det någon som tar ansvar/  
någon som håller sig i bakgrunden/osv?

Frågar de klasskompisar/frågar de lärare /frågar de oss om hjälp?

Samarbetar de "spontant"? När och hur?

### **Personligheter**

Vilka attityder finns? Hur kommer det fram?

Vilka känslor finns? Hur visas de?

Hur uttrycker de sig? tal/gester

Hur är gruppdynamiken?

### **Raster**

Kan vi hitta exempel på samarbete på rasterna?

Hur är de indelade under rasterna? Leker de i smågrupper/enskilt/stora grupper?

Använder de matte på rasterna?

## B. Interview Pupils

1. Vad tycker du om skolan?
2. Vad är det roligaste i skolan, varför tycker du att det är det roligaste?
3. Vad är det tråkigaste i skolan, varför tycker du att det är det tråkigaste?
4. Vad tycker du om matte?
5. Vad tycker du är det roligaste i matte?
6. Vad tycker du är tråkigast i matte?
7. Vad brukar du göra när du inte förstår hur du ska räkna ut ett tal?
8. Brukar du be dina kompisar om hjälp? Hur känns det att be om hjälp?
9. Har du hjälpt en kompis med i skolan någon gång? Rast/lektionstid
10. Hur känns det att hjälpa till?

# C. Interview Teacher

## Generellt

- Hur länge har du jobbat som lärare?
- Har du en klass som du följer genom lågstadiet?
- Hur ser en vanlig dag ut?
- Hur jobbar du med planering inför lektionerna?
- Har du en strukturerad plan/ go with the flow
- Hur mycket kan du följa planen eller får man vara flexibel och ändra under lektionens gång?
- Hur styrd upplever du att du är kring hur du ska undervisa/ vilka friheter har du i att lägga upp din undervisning?
- Sammanför ni de olika ämnena eller har ni mest separata lektioner med varje ämne?
- Hur gör du i så fall för att sammanföra dem?

## Digitalt

Använder ni några digitala hjälpmedel i undervisningen? Vilka? Hur?

Vad tänker du kring att använda digitala verktyg i klassrummet?

- Vad är positivt/negativt? Varför?

- I vilka situationer tycker du det fungerar bra/dåligt?

Ser du några kommande förändringar i hur digitala verktyg kommer att användas i klassrummen?

## Matte

- Kan du berätta lite om matteundervisningen? Hur brukar en vanlig lektion se ut?
- Vad tycker barnen generellt om matematik?
- Vad upplever barnen är roligt med matte? Varför?
- Vad tycker de är mindre kul? Varför?
- Finns det något i matten som många elever upplever som lätt/svårt?
- Hur jobbar ni med matteboken?
- Hur tycker du det fungerar att jobba med matteboken?
- Brukar du gå utanför matteboken och jobba med matte?
- Varför/På vilket sätt?
- Hur går du tillväga om ett barn inte förstår?
- Har ni gjort några experiment med matte eller på andra sätt jobbat med matte som är verklighetsförankrat?
- Vad har du upplevt är barnens respons på de experimenten?

## Samarbete

- Brukar barnen hjälpa varandra i matten eller andra ämnen?
- Hur då/ varför inte?
- Brukar du planera för grupparbeten?
- I vilka ämnen?
- Under hur långa perioder (långa tema-sessions/ korta sessions)?
- När eleverna jobbar i grupp och samarbetar, hur brukar du dela in dem?
- Efter kunskaper/förmågor
- Stökiga/rediga

- Barn som är vänner/ barn som annars inte umgås
- Hur många elever är lagom för samarbete?
- Samarbetar eleverna utanför grupparbeten, på vilket sätt gör de det isf?
- Hur tycker du det fungerar?
- Vad upplever du är positivt med att samarbeta?
- Vad upplever du för problem med samarbete?
- Upplever du att vissa elever gör det här mer än andra, vad tror du isf påverkar detta?
- Avslutningsvis, vad är dina bästa knep för en lyckad lektion?

### **Kort version**

- Vilken frihet har du att designa din undervisning?
- Brukar ni sammanfläta de olika ämnena eller jobbar ni mest separat? Hur gör du har att sammanfläta dem isf?
- Brukar du anordna grupparbeten i din klass?
- Hur brukar du dela in dem när ni har grupparbeten? Storlek och individer
- Brukar eleverna samarbeta även utanför grupparbeten? På vilka sätt?
- Vad använder ni för digitala verktyg i klassrummet?
- Vad är dina upplevelser av att använda digitala verktyg i klassrummet?
- Brukar ni jobba med matte även utanför matteboken?
- Har du några exempel på experiment/labbar/temaarbeten som ni gjort med matte?
- Vad är dina bästa knep för en lyckad lektion?

### **Frågor on the go**

- Hur ofta har ni mattelektion?
- Vilka arbetssätt passar de olika eleverna?
- Vad funkar i klassrummet? Varför tror du att det fungerar?
- Upplever du att det är stora skillnader i barnens kunskapsnivå och hur jobbar du för tillgodose de olika barnens kunskapsbehov?
- Hur upplever du att barnens behov skiftar (inte enbart i kunskap, finns det andra behov som skiftar mellan elever) Hur jobbar du för att tillgodose de olika elevernas behov?

# D. Interview Experts

## Inledning

Berätta om oss och vårt exjobb.

- Vill du berätta lite om vad du gör? (vilken ålder på barnen)
- Vill du berätta om projektet matematiska leksaker/matteboken?
- Kan du berätta mer om själva leksakerna/matteboken?
- Hur går ni tillväga när ni planerar workshopen på vetenskapsfestivalen?
- Vad är viktigt att tänka på?
- Vad är viktigt att tänka på när man designar för barn generellt?
- Varför?

## Digitaliserade klassrum

- Hur tänker du i allmänhet kring digitalisering i klassrummet?
- Vad kan du se för fördelar och nackdelar med digitaliseringen i klassrummet?
- Har du sett exempel på när det är lyckat med digitalisering i klassrummen och när det är misslyckat? Har du sett faktorer som påverkar detta?
- Hur ser du på att eleverna genom sin iPad får tillgång till sådant som inte är skolmaterial?
- Vad tror du är viktiga att ta hänsyn till när man designar en plattform som medierar samarbete?
- Tror du att uppgifter och design av gränssnitt kan påverka hur tillåtande och uppmuntrande elever är mot varandra i ett samarbete?
- Hur gör ni för att uppnå en tillåtande miljö där tankar och idéer inte i första hand kritiserar av andra gruppmedlemmar, utan välkomnas?
- Forskning visar på fördelar med att dela in grupper så att det finns både starka och "svaga" elever i samma grupp. Hur ser du på detta?
- Har du taktiker för att designa samarbeten där eleverna har olika kunskapsnivåer?
- Har du tips på hur man ska lyckas med ett samarbete mellan elever genom att designa uppgifter?
- Vi ska ju designa en produkt som ska användas i klassrum. Är det något som du tycker är extra viktigt att tänka på när man designar verktyg som ska användas i denna miljö?

## Workshop

Avslutningsvis, vi ska hålla en workshop på en skola där vi ska låta barnen vara med och skapa designförslag. Har du några tips till oss på vad vi ska tänka på när vi planerar och genomför den?

# E. Script for Participatory Sessions

## Introduktion - 10 min

Berätta om oss och varför vi behöver deras hjälp.

Fråga vad man ska tänka på när man samarbetar och skriv upp deras svar på tavlan.

### **Saga:**

Fyra vänner skulle tillsammans åka ut på en resa. De var alla sugna på ett äventyr och väldigt spända på vad de skulle få se på denna resa. För att förbereda sig packade de var sin väska och gick för att mötas upp på en bestämd plats. Men denna berättelse låter lite tråkig än så länge, vilka är vännerna som ska mötas upp? Hur ser de ut, vad heter de och vad har de packat med sig till resan? Ni ska få börja med att tillsammans rita de här vännerna och vi ska berätta hur ni ska göra.

## Del 1 - Vikgubbe och karaktär - 15 min

Förklara hur man gör en viggubbe genom att visa med stort papper och uppmuntra de som kan att hjälpa sina klasskamrater.

Berätta för dem att de kan måla människor, djur, fantasivarelser, eller precis vad de känner för.

Berätta att vi finns till för att hjälpa och att det är helt okej att inte hinna med. Det kan bli roliga viggubbar om delar saknas.

Ta tid och säg till när de ska byta med varandra. Om nån blir klar tidigt, be dem färglägga. När de är klara visa hur de kan använda sin kartongrulle.

### **Saga fortsättning:**

De fyra vännerna samlades på platsen de hade bestämt. Den äldsta av vännerna hade ansvar och kollade så att alla var med och alla hade med sig sin packning. Nu var det dags för de fyra vännerna att börja sin resa tillsammans. Men vart är det de ska resa då? I nästa steg ska ni tillsammans få rita hur det ska se ut där de ska resa.

## Del 2 - Miljö - 15 min

Dela ut papper, pennor, geometriska figurer, limstift.

Betona friheten de har över att skapa sina egna landskap och vikten av samarbete.

Frågor från elever

Till de grupper som blir klara tidigare föreslå att färglägga.

### **Saga fortsättning:**

De fyra/tre/två vännerna har nu rest i dagar genom landskapet ni har skapat. De har stött på hinder och löst problem tillsammans. Nu har de äntligen kommit fram till slutet av sin resa och har hittat vad de sökt. Vad är det för något de har hittat?

## Del 3 - Vinsten - 10 min

Förklara att priset ska gå att dela lika på mellan de som varit med på resan.

Förklara att de ska bestämma tillsammans ett pris och sedan rita individuellt.

En sax skulle vara ganska svår att dela lika på va? Och delar man en sax så blir den ganska svår att använda va? Men man skulle kunna hitta massa spikar att dela lika på. Men ni kanske har roligare idéer på vad de skulle kunna hitta?

### **Saga fortsättning**

De fyra vännerna är trötta men väldigt stolta att de genomfört sin resa. Inte enbart är de stolta över sig själva och varandra, de har också hittat en belöning i slutet av sin resa som de delat mellan sig själva.

## **Del 4 - Reflektion & Diplom - 10min**

Tacka för att vi fick komma

Ställ frågor till klassen

Hur tyckte ni det var att jobba såhär?

Var det något ni tyckte var svårt?

Är det något någon har att säga om den här lektionen?

Tycker ni att ni har kunnat göra de här grejerna som står på tavlan kring samarbete.

Hur gick det att komma överens om vad ni skulle göra?

Ge ut diplom och be om tillåtelse att få ta kort på deras bilder.

## **Gå runt frågor**

### **Allmänt**

Kan ni berätta vad ni har gjort för något?

Hur kändes det att bestämma tillsammans?

### **Vikgubbar**

Hur var det att göra vikkubbarna, hur ser de ut? (pratar de om dem som våra/min)

Kan du berätta om den här karaktären, vad är det du gillar med den? Varför valde du att måla den?

Vad målade ni för saker de hade med sig i packningen? Varför valde ni att de skulle ha med sig det?

### **Miljö**

Hur var det att skapa miljön? Hur gick ni tillväga?

Kan ni berätta lite om miljön? Vad tycker ni om den?

Hur gjorde ni för att komma överens om vad ni skulle måla för något?

### **Pris**

Vad var det era karaktärer hittade? Är det något ni skulle vilja ha?

Hur tänkte ni för att komma på något de kunde dela på?

Hur gjorde ni för att komma överens om vad ni skulle måla för något?

# F. Script for Formative Evaluation

Introducera oss och utvärderingen.

## Del 1 Papegoja

Visa bilder på de fyra papegojorna.

Vilken av papegojorna tycker ni bäst om?

- Varför?
- Varför tycker ni bättre om den än de andra?
- Vilken tycker ni minst om?
- Varför?

## Del 2- Måla av Papegoja -

Förklara hur de ska gå tillväga och betona att det inte är viktigt med att fylla i rutorna helt. Ge dem olika färger på pennor och instruera dem att de har ansvar för att måla de färger de har.

Frågor att ställa vid olika situationer som kan uppstå:

1. Elev säger till vilken ruta den andra ska måla utan närmare förklaring

Hur vet du att den rutan ska vara i den färgen? Kan du förklara?

2. Eleverna målar på utan ansträngning och utan att behöva hjälp.

Hur vet ni att ni målar rätt rutor? Kan ni förklara?

Vänd på pappret och prova om det går för dem då, om det blir svårare.

3. De förstår inte hur de ska tänka och ber om hjälp.

Börja uppifrån och ned och förklara med hjälp av att räkna rutor.

Hur tycker ni att denna uppgift gick?

Hur var det att samarbeta?

Var det något ni tyckte var svårt?

Var det något ni tyckte var lätt?

Hur tycker ni att det är att förklara för andra hur du har tänkt när du har räknat ut en matteuppgift eller löst ett problem?

## Del 3 - Bergsvandring

Ge dem varsin papegoja som de valde i del 1 och ta fram planen med bergen på.

- Ni ska gå till ett av bergen, vilket berg skulle ni vilja gå till?

- Varför?

- Varför tycker ni bättre om den än de andra?

- Vilken tycker ni minst om?

- Varför?

Frågor om eleverna inte diskuterar formspråk.

Vilket berg tycker ni bäst om?

- Varför?

- Varför tycker ni bättre om den än de andra?

- Vilken tycker ni minst om?
- Varför?

Papegojan är lite osäker på avståndet och skulle vilja att ni kollar lite på kartan och ser hur långt det är mellan bergen innan ni bestämmer er för vart ni ska gå.

Till Klossberget är det 20 mil att gå. Skriv in det på första sträckan.

Måla samtidigt i streckan med färgpennan för att visualisera.

Denna sträcka är 8 mil kortare. Hur långt är det mellan Klossberget och Klippberget?

Måla samtidigt i streckan med färgpennan för att visualisera.

Denna sträcka är 4 mil kortare än den förra. Hur långt är det mellan Klippberget och Gräddberget?

Måla samtidigt i streckan med färgpennan för att visualisera.

Denna sträcka är 9 mil längre än den förra. Hur långt är det mellan Klippberget och Skräckberget?

Måla samtidigt i streckan med färgpennan för att visualisera.

Hur långt är det från start till Skräckberget?

Frågor om en elev tar över

Hur räknade du ut det? Kan du förklara hur du gjorde?

Frågor om eleverna räknar väldigt fort utan att diskutera med varandra

Hur räknade ni ut det? Kan ni förklara hur ni gjorde?

Det är för svårt - Guida dem i steg

Papegojan säger till er att hen vill max flyga 42 mil, annars blir den för trött. Vilka berg kan ni gå till då?

- Hur tänkte ni när ni kom fram till att det är de bergen ni kan gå till?

- Är det några andra berg ni kan gå till?

Hur tycker ni att detta var?

Hur var det att samarbeta?

Var det något ni tyckte var svårt?










Var det något ni tyckte var lätt?

Hur hade det varit att lösa uppgifter som denna tillsammans på mattelektionerna?

Om ni fick välja fritt, vad skulle ni döpa matteappen till?

# G. Activity System Model - User Study in Context

## Index

-  Pupil
-  Teacher or Author
-  Class or Group
-  App
-  Mathematics book
-  Mathematics game
-  Language
-  Workshop material 1
-  Workshop material 2





# Matches & Mismatches

The image displays a matching exercise with two columns of circular diagrams. Each diagram contains a tree structure with various icons and text. The diagrams are color-coded and arranged in two vertical columns. The left column has a gap in the middle, and the right column has a gap in the middle. The diagrams are labeled 'Action' and 'Activity' at the bottom of each column.

**Left Column Diagrams (from top to bottom):**

- Green circle: Tree with pink flowers, a person, and a smartphone icon.
- Pink circle: Tree with blue flowers, a person, and a smartphone icon.
- Blue circle: Tree with yellow flowers, a person, and a smartphone icon.
- Yellow circle: Tree with blue flowers, a person, and a smartphone icon.
- Green circle: Tree with pink flowers, a person, and a smartphone icon.
- Pink circle: Tree with blue flowers, a person, and a smartphone icon.
- Teal circle: Tree with green leaves, a person, and a smartphone icon.

**Right Column Diagrams (from top to bottom):**

- Green circle: Tree with pink flowers, a person, and a smartphone icon.
- Pink circle: Tree with blue flowers, a person, and a smartphone icon.
- Blue circle: Tree with yellow flowers, a person, and a smartphone icon.
- Yellow circle: Tree with blue flowers, a person, and a smartphone icon.
- Green circle: Tree with pink flowers, a person, and a smartphone icon.
- Pink circle: Tree with blue flowers, a person, and a smartphone icon.
- Teal circle: Tree with green leaves, a person, and a smartphone icon.

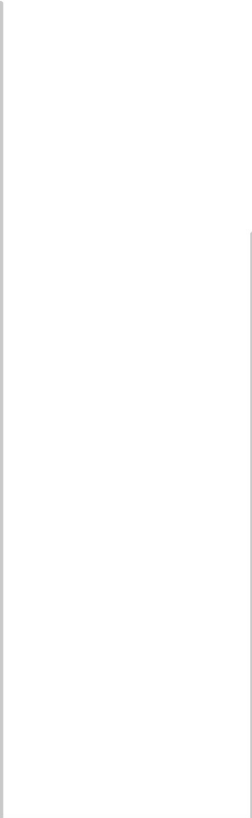
**Labels:**

- Left Column: 'Action' (bottom), 'Activity' (bottom)
- Right Column: 'Action' (bottom), 'Activity' (bottom)

**Action**

**Action**

**Action**



**Action**

**Action**

**Action**

**Action**

**Activity**

**Activity**

**Activity**

**Activity**

# H. Script for Summative Evaluation

Introduction about us and the evaluation. Tell them about how to navigate the iPad and that the answers should be written on the paper sheet. Let them do as well as they can during the evaluation and help them if needed. Follow the checklist below and take notes and ask questions based on the checklist.

## **Shared group meaning:**

What are you going to do today?( ask after they have selected the fish/been introduced to the llamas)

What have you done today? (ask after they have finished the assignments)

## **Disagreement:**

Do not come to an agreement but there is a discussion

Do not come to an agreement and there is no discussion

What are you thinking now?

What would help you to move forward now?

They find a compromise

They build on each other's knowledge

Are you in agreement?

How did you come up with this?

Was there anything that helped you to come up with this?

Do they celebrate in any way? How?

## **Errors (quantitative by counting)**

How many errors are made? (counts from when they have written on paper)

How many are found by the pupils themselves without hints?

How many are found with one hint?

How many are found when pointed out?

How many are corrected?

Do they discuss errors? What do they say?

## **Inclusion**

Are both of the pupils filling in the answers? (one colour each/take photo)

Are both of the pupils calculating or giving inputs on how to solve the problem?

## **Discussion and explanation (quotes)**

## **Interest**

Will they comment on the visuals?

What are they commenting?

For how long do they comment on the visuals?

## **Visual support**

Do they use the visual support to explain to each other?

Do they interact with the visual support?

Praise their classmate (photos of the rewards and write down observation and quotes)

What are they writing to each other?

How is it received?

Do they keep them or leave them?

## **Interview questions**

What did you think of this assignment?

Was there something new?

Did you learn anything today? If so, what?

What do you think of the characters?

How did you go about for both to be included?

Would you have liked to change something so it would have been easier for both of you to be included?

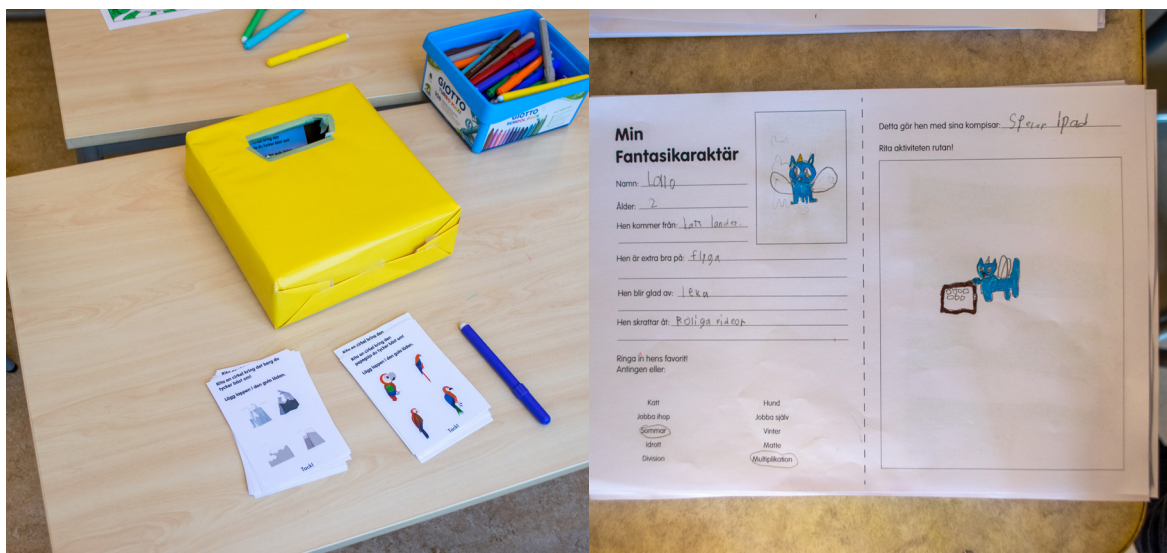
Were you able to discuss the assignments with each other?

What made it possible/difficult for you to discuss the assignments with each other?

Did you understand what to do? Did you find anything complicated?

# I. Methods for Inclusion of Pupils Who Could Not Participate

A voting box was used during the summative evaluation. The aim of this assignment was mainly for all pupils to feel included but the authors were also hopeful that quantitative data could be collected on the pupils' esthetical preferences. A cardboard box resembling a Swedish post box was constructed and the pupils were provided with ballot paper with images of the four different kinds of parrots and mountains. This material was left given to teachers during the evaluation however, it was only during the second evaluation that the teacher presented it to the pupils. The box and the votes were collected after the evaluations were finished. When counting the votes it became evident that the authors could not draw any conclusions from the results as only a handful of pupils voted (a total of eight ballots were collected). These votes have therefore not been included in the result.



"My friends" was used during the summative evaluation. The aim of this assignment was mainly for all pupils to feel included and to collect data that would add to the results of phase two. This assignment was inspired by books where the reader can fill in information about themselves and their friends. In the assignment the pupils were able to draw their own imaginary character and assign them a name, an age and origin. Further, the pupils could for example fill in what makes the character happy and draw an activity that the character enjoys. This data was viewed mainly as supportive data since the authors were not able to be present when the characters were created or ask the pupils questions.

During the Evaluation of initial concepts the pupils who could not attend were given a booklet of the images. They were also able to write comments on the different concepts.

