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Guiding Research Question Formulation in a Web-Based Lab

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Abstract

Inquiry-based learning can help develop scientific understanding in children. Naturalis, the biodiversity centre in Leiden, wants to utilise inquiry-based learning to encourage children to conduct their own research projects using the data collection of Naturalis, made digitally available through a web-based nature lab. However inquiry-based learning can increase cognitive load to such an extent that learning is impaired. Guidance can reduce the cognitive load to a manageable level. This thesis examined the effect of digital guidance on the process of formulating a research question. The data set used was on bees. First preliminary research was conducted to investigate the quality of the research questions children formulate. Then three paper prototypes, the Knowledge-Curiosity tool, the Agent tool and the Word-block tool, were developed and tested. Based on the results of the paper prototype testing, the knowledge-curiosity tool and the agent tool were further developed as digital prototypes. These two digital prototypes were tested with 40 first-year VWO high school students. The results showed that there was a slight increase in the quality of the written research questions if the students received guidance from either tool. There was no significant difference between the quality of the research questions written with the agent tool and the knowledge-curiosity tool. However the questionnaire results showed that the students did not feel like the guidance tools helped them write better research questions. We conclude that digital guidance can help children write research questions of a better quality, but that metacognitive activities should be supported to ensure the user is aware of the learning process. This thesis provides us with insights that can help improve (digital) guidance in inquiry-based learning as well as calling our attention to important considerations that need to be made when designing digital guidance tools.

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Chapter 1

Introduction

Learning to ask questions about concepts and observations helps the development of scientific understanding in children. Nurturing scientific understanding in children is important as they are the worlds' future scientific researchers. Scientific researchers help solve problems like environmental and economical problems, but they also help humanity to keep innovating and improving on existing technology. The motive for scientific research is either human need or human curiosity (or both). An example of scientific research that has arisen from human need, are the Dutch Deltaworks, built to prevent the land from flooding. Space travel on the other hand is scienctific research that is mainly based on human curiosity, as humans have no particular need to explore space. Children are naturally curious and ask questions aplenty, however these tendencies do not usually lead to the child conducting scientific research. The child has to be taught *how* to formulate questions and how to find the answers to those questions in a scientific, structured way.

Naturalis, the biodiversity centre in Leiden, has made it their goal to raise children's curiosity for science. They possess a huge collection of which a part is on display in the Naturalis museum. Now Naturalis wants to make part of that data collection digitally available through a web-based Nature lab. The purpose of this Nature lab is to encourage children (10-18 years) to explore the data collection and conduct their own (small) research projects. A first version of the Nature lab contained the data from a nationwide bee and bumblebee count held in April 2018 in the Netherlands. The Nature lab also contained tools that enabled children to view and examine this data. In the future more data will be made available through the Nature lab and more tools that help children explore and examine the data collections will be added.

The Nature lab will be focused on helping children conduct research projects and through these research projects, simultaneously teach them about science. Learning through research is the principle of inquiry-based learning. In inquiry-based learning children follow the phases of the inquiry cycle to conduct a research project. Studies have shown that inquiry-based learning methods are more effective than other more traditional teaching methods (Abdi, 2014; Hermann, 1969), as inquiry-based learning encourages active participation that promotes children's meaningful learning (Bielik & Yarden, 2016).

Inquiry-based learning involves complex tasks that increase the cognitive load of children. If the cognitive load is increased to a level that is no longer manageable by the children, learning might be impaired. Guidance through the tasks can help reduce the cognitive load back to a manageable level (Hmelo-Silver et al., 2007). There exist a multitude of guidance techniques that can be applied to the different phases of the inquiry cycle. Some guidance techniques can be applied to multiple phases, others are very specifically suitable to one phase. Which type of guidance technique is best suited depends heavily on the situation, but it has been shown that inquiry-based learning with guidance, is more effective than inquiry-based learning with no guidance (De Jong & Van Joolingen, 1998).

In this thesis the process of formulating a research question and how to support that process is the main interest. Not all children will need the same amount and type of assistance, as their initial skill level will vary. The purpose of this study is to find a sufficiently flexible method to support the process of formulating a research question. The research question is: *How can we utilize digital guidance to help children formulate good research questions?*

In this thesis the relevant theoretical background will be explored to gather design ideas for a digital guidance tool. The preliminary research that was conducted to investigate the quality of the research questions children write without guidance will be described. Then the process of constructing paper prototypes for three guidance tool ideas and the results of the paper prototype testing will be discussed. After that the development of the digital guidance tools and the experiment conducted to test those guidance tools will be explained. The results of the digital prototype testing and their implications are discussed. Finally, how the findings of this thesis can inform the design of future versions of the Nature lab will be discussed.

Chapter 2

Theoretical background

In order to understand how the process of formulating research questions can best be guided, we first need to understand the process of formulating research questions in the context of inquiry-based learning, as a research question is influenced by other processes in the inquiry cycle. In section 2.1 the term inquiry-based learning is defined and the phases of the inquiry cycle are explained. The questioning phase will be discussed in more detail as we need to have a deeper understanding of the place of this phase in the inquiry cycle. Finally, non-digital and digital inquiry-based learning are compared. In order to understand the best way to provide guidance for inquiry-based learning, we need to understand the cognitive and metacognitive activities underlying the inquiry-based learning process. In section 2.2 we will describe some cognitive and metacognitive activities relevant to inquiry-based learning. We also need to explore the guidance techniques available to support these (meta)cognitive activities, which will inform the design of the tool we aim to built during the run of this project. In section 2.3 different guidance techniques are explored using several examples from the literature. Finally, section 2.4 will provide an overview of the design principles the guidance techniques are based on, the cognitive activities related to them and the inquiry cycle phase in which the design principles are best applied.

2.1 Inquiry-based learning

Inquiry-based learning is an educational method in which students construct knowledge and conceptual understanding by using methods similar to those used by professional scientist (Schraw & Lehman, 2001; Keselman, 2003). These methods include posing questions, gathering data, interpreting the data, and then formulating an explanation, based on the gathered data, that answers the question (National Research Council, 2000). Inquiry-based learning belongs, like other educational methods such as problem-based learning and case-based teaching, to the group of inductive learning methods (Prince & Felder, 2006). In inductive learning a student is first presented with a real-world problem, a case study or a set of data. The student needs to have knowledge of facts, rules and procedures to solve the problem, analyze the case study or interpret the data. As the student is working on the material, gaps in their knowledge may become apparent. The student then has to fill the gaps in their knowledge themselves or the information can be provided to them, once they realise what information they need. In an inductive teaching method the teacher mainly has a facilitating role, helping the student where needed.

This is opposed to a deductive learning method which might be viewed as a more traditional teaching method, where the teacher lectures the students on some subject, demonstrates the application of the explained subject and then assigns the students homework to practice the application, without providing real-world context. The real-world context plays an important role in motivating the student as it demonstrates *why* the student has to know about a certain subject, which is a better basis for learning than the vague idea that the knowledge will somehow become relevant in the future (Prince & Felder, 2006).

Experiments in which inquiry-based learning methods are compared with more traditional teaching methods show that performance in class is better when students are instructed through an inquiry-based learning method (Abdi, 2014; Pedaste et al., 2015; Lazonder & Harmsen, 2016). Different authors use different performance measures in their comparative studies. Most authors apply some form of pre- and post-test to measure academic achievement; that what the student has gained in knowledge and is able to apply on a test. Then there is a variety of skills that have been measured, such as problem solving and scientific reasoning skills (Pedaste et al., 2015; Wu et al., 2016) and process skills and analytic abilities (Shymansky et al., 1990). Inquiry-based learning has a positive effect on all these skills. Furthermore it has been shown that student motivation and attitude toward science learning is improved by inquiry-based learning (Hwang et al., 2015; Hsu, 2016). Motivated students will be more actively involved in the learning process, which results in better retention of the learned information (Anderson et al., 1998). The studies showing pre- and post-test results show that inquiry-based learning can have a direct positive effect on students' academic performance in class. Some of the other studies mentioned above, reporting on the improvement of related skills or an increase in motivation, show inquiry-based learning can also have an indirect effect on students' performance. An indirect effect might not always be as easily noticeable, but might be just as important as the better academic performance.

Besides empirical support, there is also strong neurological and psychological evidence for inquiry-based learning. All learning is strongly influenced by prior knowledge (Bransford et al., 2000); How well something is learned depends on how well the student is able to connect the new knowledge to the already existing cognitive structure. This is why an inductive teaching method works very well, as the emphasis is on a real-world context students can relate to. The familiarity of the student with the real-world context can help embed the new information into the cognitive structure, but the student is also encouraged to use the prior knowledge they have on the subject to solve the problem, which helps forge new connections between prior knowledge and new knowledge. The similarity between course work and real-world work situations will also increase the likelihood of the transfer of skills and knowledge (Bransford et al., 2000). Neurological and psychological studies show that inquiry-based learning cannot only have a positive effect on the short term, but also on the long term, as an increased likelihood of transfer of skills and knowledge ensures that the learned material can also be useful in future scenarios.

As an inductive teaching method, inquiry-based learning has been shown to have a positive effect on students' performance by empirical, neurological and psychological studies. The effect on the performance can be both direct, by increasing test scores and indirect, by improving students' motivation for example. Naturalis' choice to use inquiry-based learning to encourage children to conduct their own research projects and this way learn about the subject matter, is supported by the literature. This way the children will hopefully be able to use the things they learned in the Nature lab in their future (school) careers.

2.1.1 The Inquiry cycle

In section 2.1 the learning outcomes of inquiry-based learning were discussed. The end-goal of inquiry-based learning is to teach students about a certain subject, however as inquiry-based learning depends on the students knowing about inquiry methods, part of using an inquiry-based teaching method often involves teaching the students about how to perform an inquiry as well.

Inquiry-based learning usually follows the phases of the inquiry cycle. Definitions of the phases the inquiry cycle contains differ widely. Pedaste et al. (2015) conducted a literature study in which they reviewed 32 articles. These articles all gave a definition of the inquiry cycle or of part of the inquiry cycle. Pedaste et al. (2015) compiled from these different definitions a more general inquiry cycle, which was incorporated in a framework for inquiry-based learning (see Figure 2.1). The phases of the inquiry cycle in the framework they identified were: Orientation phase, Conceptualization phase, Investigation phase, Conclusion phase and Discussion phase. These phases are each divided into sub-phases that are connected to each other. A short description of each phase will follow.

The *Orientation phase* contains those activities necessary for a student to get started with a new research topic. These activities include observation of the environment and exploration

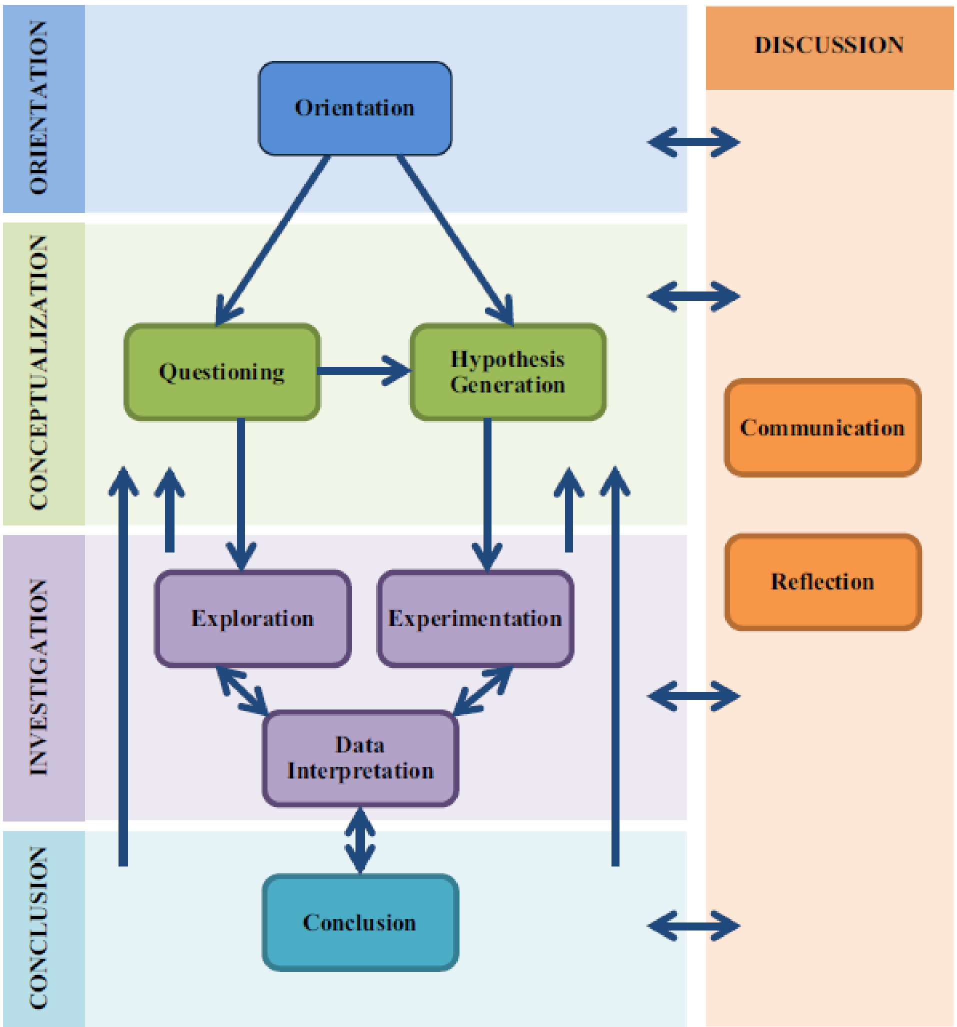


Figure 2.1: Inquiry-based learning framework as defined by Pedaste et al. (2015)

of the topic, through reading for example. This should lead the student to insights about the scientific questions that are related to the research topic. The observations and insights should get the student interested in and engaged with the research topic. The outcome of this phase is often a sort of problem statement.

The *Conceptualization phase* includes two sub-phases called “Questioning” and “Hypothesis Generation”. The “Questioning” phase concerns the activity of formulating a more specific question from the questions which might have been considered in the Orientation phase. This question can be a specific research question or a more open question about the research topic. “Hypothesis Generation” refers to the process of compiling and analysing information from different sources in order to predict an answer to the stated research question. The outcome of the Conceptualization phase is one or multiple research questions and hypotheses.

The *Investigation phase* includes the sub-phases “Exploration”, “Experimentation” and “Data Interpretation”. “Exploration” refers to a less formal method of collecting data, during which no particular hypothesis is kept in mind. “Experimentation” on the other hand refers to a data collection method that is well planned beforehand and where collected data is used as evidence for a certain hypothesis. Finally, the “Data Interpretation” sub-phase is used to describe all kinds of data-analysis activities, which can help extract information from the collected data that might help answer the research question. The outcome of the Investigation phase is a set of data and an analysis of that data.

Finally, Pedaste et al. distinguished between a *Conclusion phase* and a *Discussion phase*. The Conclusion phase describes the activities of drawing a conclusion from the data collected and analysed in the Investigation phase. The Discussion phase includes other activities such as communicating the conclusion and discussing the results with others.

In this thesis the definition of the inquiry cycle as defined by Pedaste et al. (2015) will be used. Any references to the phases by name will refer to activities such as described above.

2.1.2 Questioning phase

The focus of this thesis is on finding out how to guide the formulation of research questions in children. As such the Questioning phase should be examined and understood in more detail than in the cursory description given in section 2.1.1. This section will zoom in on the Questioning phase.

The input to the Questioning phase is a problem statement as formulated in the Orientation phase and the gathered scientific questions about the research topic. This input can be used to help formulate one or more research question(s) that form the output of the Questioning phase. This thesis will only concern itself with the connections going out from the Questioning phase. The connections from different phases pointing back to the Questioning phase in Figure 2.1 will not be considered.

In school settings the source of the research question can differ. The teacher might provide a research question to the students, the students might get the assignment to come up with a certain research question regarding a specific topic or the students might be free to explore a research topic on their own and formulate a research question based on their interest in a topic. What kind of assignment is given to students might depend on their age and skill level. Older students might already be able to perform their own orientation and formulate a research question, while younger students might benefit from getting the research question from their teacher so they can get familiar with the inquiry process first. Naturalis’ Nature lab is aimed at high school students. As the age and skill level of first-year high school students is generally quite different from the age and skill level of high school students in their final year, it should be investigated what source of research questions suits high school students of different ages best. If necessary the Nature lab should allow and support different sources of research questions. The tool developed in this thesis is aimed specifically at children aged 12-13, to find at what level these children are, a preliminary experiment is conducted (see Chapter 3).

The Questioning phase is one of the most important phases of the inquiry cycle as it fuels the rest of the cycle. In the Hypothesis Generation phase the hypothesis is the predicted answer to the research question. The investigation methods used in the Experimentation and Exploration phase depend on the type of research question that is asked in the Questioning phase. Finally, in the Conclusion phase, the interpreted data must lead to a conclusion that answers the research question. This way the research question influences the proceedings within the phases of the inquiry cycle and their outcomes.

The type of research question determines the investigation methods that are used in the Experimentation or Exploration phase. A set of investigation methods makes up a certain research type. Alvesson & Sandberg (2013) identified four types of research questions: Descriptive, Comparative, Explanatory and Normative. Their research is based on a paper by Dillon (1984) in which he presented a detailed way of classifying types of research questions. He argued that there is also a hierarchy in these types of research questions. Meaning that to be able to ask meaningful comparative research questions, the descriptive research questions should first be answered, as you cannot compare something, without knowing the essence of it. Just as definitions of the inquiry cycle differ, definitions and names of the research types differ. In this thesis we will use the research types identified by Alvesson & Sandberg (2013).

Another method of classifying research questions that we will use in this thesis, is Bloom's taxonomy (Bloom, 1956). Bloom's taxonomy is generally used to help educators develop learning objectives for their lessons. It provides a way of organizing the level of thinking skills necessary to complete certain objectives. Since Bloom first published this taxonomy, ideas about education have changed and developed. As such Bloom's taxonomy has been adapted to fit these new ideas on education, the taxonomy used in this thesis can be found in Appendix A . Bloom's taxonomy defines six cognitive levels: Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation. The cognitive levels are ordered, so for the Knowledge level lower level thinking skills suffice, while for the Evaluation level, higher level thinking skills are needed. A set of activities and a list of key words are associated with each cognitive level, which we will use to classify the research questions with Bloom's taxonomy. This provides us with an overview of the cognitive levels needed to investigate and answer the research questions.

There is a wide variety of research questions that can be asked. However, different types of research questions and research questions of different cognitive skill levels, can have different characteristics. This means that stating one definition of what a good research question is, is hard.

What a good research question is, is in most studies we found ill-defined. As the goal of this study is to built a tool that helps students formulate research questions, it is important to have a clear definition of what is considered a good research question. Cuccio-Schirripa & Steiner (2000) gave the following definition of a good research question: (1) to answer the question an experiment has to be conducted and data has to be collected, (2) the question includes a dependent variable, an independent variable that can be manipulated and the connection between those two, (3) the answer to the question is not known to the student before hand. Bielik & Yarden (2016) have somewhat different criteria a research question should meet: (1) the question should be related to the research topic, (2) the question should consist of dependent and independent variables and the relationships between them, and (3) the questions should be appropriate for research under the limitations of complexity, available equipment, and time. The first and third constraints by Cuccio-Schirripa & Steiner and the first constraint by Bielik & Yarden are general constraints that indicate that the question should be a relevant, scientific question to which the answer is unknown to the student. The second constraint by Cuccio-Schirripa & Steiner and the second constraint by Bielik & Yarden are constraints that describe the structure a research question should have. Finally, the third constraint mentioned by Bielik & Yarden are practical constraints that ensure that the question is answerable. These practical constraints depend on the context of the project, which should thus be taken into account when defining what a good research question is.

The goal of Naturalis is to make children curious about science and encourage them to ask all kinds of research questions that belong to different research types. So the definition should not exclude too many types of research questions. Taking this and the definitions from the literature into consideration and keeping the practical constraints in mind, we can define a “good research question” as follows: a research question is of a scientific nature and contains at least one variable that is answerable in the context of the Nature lab. The research question should be interesting to the student and ideally it is a question the student does not yet know the answer to.

2.1.3 Digital inquiry-based learning

Normal inquiry-based learning was already briefly discussed in section 2.1. There it was stated it is an inductive learning method and that the students learn by the method exposing gaps in their knowledge and encouraging them to fill these gaps by means of an investigation. This encourages the students to actively process the information, they have to think about all the ways in which the new information is connected to their prior knowledge and can thus make more connections in their cognitive structure, which helps them memorize the information better. Students actively processing information will perform better over the long term (Lonka & Ahola, 1995). This is why studies generally find that inductive methods are more effective than deductive methods.

Digital inquiry-based learning differs from normal inquiry-based learning in one main aspect: there is no human teacher. Although it might be possible for a digital system to use some of the same teaching methods as a human teacher, for some teaching methods a digital system will have to use alternatives. Presenting a real-world problem, case or a set of data and providing the student with information to read might be done by a digital system in a similar way as a human teacher might present it. A discussion about a research topic between the students and the teacher, which promotes self-reflection and more meaningful processing of the topic by the students (Bielik & Yarden, 2016), can be realized by a forum or other communication tool such as in Hsu (2016) and will have a similar effect as a real-time class discussion. On the other hand in a “normal” classroom setting a human teacher will be present to help and encourage students during the learning process or discuss ideas in real-time, a digital system might not be able to provide such support, unless specifically programmed to be able to respond to the progress of the student. Even then this interaction between a digital teacher and the student will not be the same as the interaction between a human teacher and the student, as a digital teacher will lack emotion and empathy. Moreover, a teacher knows their students and can provide help on a level suitable to the student, a digital system does not have this advantage. It has to provide help on a suitable level in a different way.

A digital system also has advantages over normal inquiry-based learning. It is easier to keep track of and give an overview of the student’s progress. Furthermore a digital system is always available to the student, so they can work on their assignments in their own time. Finally, a virtual lab may give the student more experimentation opportunities than are available in the “real world” (due to space and/or financial limitations of the school for example).

It is important to keep in mind the advantages and limitations of digital inquiry-based learning systems, so that we can design a system that uses the advantages a digital system offers in an optimal way and that we can compensate for its limitations, by either designing the system around the limitations or by constructing a lesson plan that helps the teacher fill the gaps.

2.2 Cognitive and Metacognitive activities

To be able to build the best tool we need to be aware of the metacognitive and cognitive activities underlying the inquiry-based learning process as they might provide insight into how to best teach inquiry-based learning.

Inquiry-based learning is a complex learning method that can comprise a wide range of cognitive and metacognitive activities. Cognitive activities in learning are those activities that help with encoding, memorizing and recalling the information (Schraw et al., 2006). In the case of inquiry-based learning these activities are mainly the activities that make up the steps of the inquiry cycle, as the theory is that students learn about a certain topic by performing an inquiry. Examples of those activities are: formulating research questions, gathering information from various sources, sorting and analysing the information and integrating different pieces of information to answer the research question (Jukes et al., 2000). Metacognitive activities can be divided into two categories: metacognitive knowledge and metacognitive regulation (Quintana et al., 2005). Metacognitive knowledge is the awareness about the cognition that one possesses, like how good a learner one is, but also task knowledge and strategic knowledge, that comprise knowledge about the cognitive demands of a task and the general strategies that may be used to tackle a task. Metacognitive regulation refers to activities such as task planning, the monitoring of progress, problem solving and reflection to improve future performance. So cognitive activities are activities that are needed to complete a task, while metacognitive activities help regulate the cognitive tasks.

Zepeda et al. (2015) conducted a study with eight-grade students where one group received metacognitive instruction and practised problem-solving, while the other group only practised problem-solving. Their results showed that metacognitive instruction had a positive effect on students' performance on a conceptual physics test and increased students' motivation. Metacognitive instruction also had a positive effect on transfer of skills and knowledge, as students' that received metacognitive instruction performed better on a novel self-guided learning activity. Combining metacognitive instruction with inquiry-based learning might be able to help reinforce the positive effects of inquiry-based learning explored in section 2.1.

Without metacognitive instruction, metacognitive knowledge may be implicit and students may not be consciously aware of metacognitive regulation taking place (Schraw et al., 2006). This is not necessarily a problem in lower science education levels, but awareness of metacognition helps the student become a better learner and may even be essential on higher science education levels. Here a digital inquiry-based learning program may have an advantage over normal inquiry-based learning, as it can more easily give a(n) (statistical) overview of the progress the student has made.

The next section will explore further how inquiry-based learning can be taught through a digital system and how guidance can be provided to support cognitive and metacognitive activities.

2.3 Guidance Techniques

Guidance refers to the concept of providing the learner with (instructional) support to help the learner accomplish a task, which the learner could not have accomplished without external support (Proske et al., 2012; Quintana et al., 2005). The end goal of guided teaching is to enable the learner to perform a task without aid. The amount and level of guidance needed will differ per learner, therefore different types of guidance are required. The guidance can be provided by a (knowledgeable) adult or peer, by written instructions, but also by computer software. In this thesis guidance through computer software is the main interest.

2.3.1 Types of Guidance

The level of guidance a student needs depends on the student's personality, motivation and level of knowledge and skill, but also on the cognitive and metacognitive activities needed in a task. One type of guidance could not offer the best support for every individual. Lazonder & Harmsen (2016) conducted a literature study in which they compared the effectiveness of different guidance types for different age groups. They identified six types of guidance: process constraints, status overviews, prompts, heuristics, scaffolds and explanations. Process constraints are the most general form of guidance, meant for more mature learners, who already mastered most inquiry skills. Explanations are the most specific type of guidance, meant for learners who are new to inquiry-based learning. Every type of guidance in between gets progressively more specific with regards to the amount of detail in the instructions provided to the learner to help them accomplish the next step.

Process constraints organise the inquiry task into a series of manageable subtasks (Lazonder & Harmsen, 2016). This reduces the complexity of the inquiry task. This type of guidance is meant for more mature learners, with developed inquiry skills.

Status overviews summarise the performance of the learner, this summary can then be used by the learner to adapt their behaviour. As the decision to change the behaviour is up to the learner, this type of guidance is for independent learners. This guidance type is especially useful for learners who work in groups as this type of guidance can help less active learners to increase their participation (Janssen et al., 2007).

Prompts are cues repeated after a certain interval to remind the learner to execute a certain action. This type of guidance tells the learner *what* to do when, but not *how* to do it. Therefore this type of guidance is for less experienced learners, who do have a basic understanding of inquiry learning.

Heuristics tell the learner what to do and how an action could be performed. As such this guidance type is suited to learners who are still in the process of developing their basic inquiry skills.

Scaffolds provide even more support than heuristics, by not only telling the learner what to do and how to do it, but also offering specific means to execute the action the learner has to take. The goal of scaffolds is to keep the cognitive load on a manageable level for students, if the skill-level of the student increases the scaffold can gradually be removed. This type of guidance can for example be used for children in elementary school and support them in their learning process through middle school and high school.

Explanations specify in detail how to perform an action. They can be given either before or during the inquiry task. This type of guidance is for the learners who are very inexperienced and are new to inquiry-based learning.

Lazonder & Harmsen (2016) concluded that the specificity of the type of guidance was inconsequential, however learners who received some type of guidance outperformed learners who did not receive any guidance. This means that which type of guidance to use depends on the goal of the tool and which type fits the platform the best. One or more of these guidance types can also be chosen based on the age and skill of the learner. More explicit instructions might still be more suitable for younger learners, even though Lazonder & Harmsen (2016) did not find any significant effects of guidance type on the performance of learners of different ages.

2.3.2 Examples of guidance

Over the past several decades multiple systems have been developed that provide guidance for science learning and/or inquiry-based learning. Perhaps such systems can help identify examples of design principles for software based guidance, that can be applied in the design and development of the research question guidance tool we will implement in this project.

Inquiry Island White et al. (2002) developed Inquiry Island, a software tool containing advisors that supported students through every step of the inquiry cycle. Each advisor has a certain expertise. The aim of Inquiry Island is to make cognitive, social and metacognitive processes explicit to and useable by the students (White et al., 2002). Aside from using the advice given by the different software agents, the students can also modify and add to the advice given by the agent. This encourages reflection on the inquiry process. The types of guidance as identified by Lazonder & Harmsen (2016) used in this system are Process constraints (the steps of the inquiry cycle are laid out for the student in the Research Notebook) and Heuristics (the advisors don't only point the student to relevant activities, but also give advice on how to approach the activity). The system also includes sliders in the Research Notebook which are meant for the students to self assess and reflect on the quality of the work they did. In this way Inquiry Island encourages metacognitive activities.

Betty's brains Although the Betty's brains program was not specifically developed to support the inquiry process, it was aimed to improve science learning in students. Betty's brains uses the learning by teaching paradigm (Bargh & Schul, 1980; Benware & Deci, 1984; Biswas et al., 2001). In the learning by teaching paradigm a student has to teach a fellow student, teacher or software program about a certain topic, through this process the student learns about the topic themselves, because to be able to explain something, you have to understand it. In Betty's brains, the student has to teach Betty, an agent, about certain science topics. The student has to construct a model that represents the knowledge Betty has about a certain topic. Important in this model are the causal relationships between different variables. Betty can be quized and the answers she gives to the questions, provide feedback on how good the model was that the student constructed. Another agent, Mr. Davis can be called upon to provide help during the task of constructing the knowledge model for Betty. The types of guidance as identified by Lazonder & Harmsen (2016) used in this system are Process constraints (there is a limited amount of subtasks the student has to execute to reach their goal), Heuristics (such as were provided by Mr. Davis on demand) and Status overviews (the system provides an overview of which part of the model Betty used for answering a quiz question, showing the student which links were incorrect if any). Many of these guidance techniques were also aimed to improve metacognitive skills in students. Furthermore Betty's brains depends on the effects of social interactions to influence student behaviour as Betty and Mr. Davis interact conversationally with the students and students felt a certain responsibility to let Betty perform well on the tests (Biswas et al., 2015).

Go-Lab De Jong et al. (2014) developed the Go-Lab (`https://www.golabz.eu/`[1]), a big project spanning multiple European countries and involving hundreds of schools. The Go-Lab is an online platform that enables teachers to create their own "science spaces" and make those available to students to use in their learning activities. These science spaces often include a virtual laboratory in which students can investigate the science topic with simulated virtual equipment. The Go-Lab is designed to incorporate the different phases of the inquiry cycle, each listed in

[1] Accessed on 11/07/2019

a separate tab. For each phase in the inquiry cycle there are a couple of guidance tools, based on the types of guidance identified by Lazonder & Harmsen (2016). There is a *Concept Mapper* in the Orientation phase which helps students get an overview of important concepts and their relations in a certain scientific domain. A *Hypothesis Scratchpad* and a *Questioning Scratchpad*, which are scaffolding tools that offer an overview of possible terms which can be selected to form a hypothesis or a research question. These tools also allow students to add their owns words (see Figure 2.2). The *Experiment Design tool*, helps students to make an experiment without confounding variables. It can provide a list of variables and the students then have to drag these variables to different boxes that indicate which variables will be varied, which will be kept the same and which variables have to be measured. Go-Lab will give a warning if the student tries to vary two or more variables, which might become a confounding variable. This tool also allows the student to run the experiment and see what the outcome might be.

Furthermore Go-Lab offers the inclusion of more general basic tools such as a calculator. The tools are both independent and integrated, meaning that if you are in the Conclusion phase of the inquiry cycle, the student could still look at the Hypothesis Scratchpad.

2.4 Summary of selected design principles

The goal of constructing this theoretical background was to find the theoretical context for this thesis and find design principles to guide the development of the tool that will be discussed in Chapter 5. The theoretical context was found in the form of the inquiry cycle and the theory of inquiry-based learning. It was also found (meta)cognition plays an important role in the process of learning.

The examples discussed in section 2.3.2 give an idea of which guidance techniques have been used in the past. From these examples some design principles were selected. For example in Inquiry Island and Betty's Brains the Island advisors and Mr. Davis respectively support the student in organising the metacognitive knowledge they have of inquiry processes. The Island advisors and Mr. Davis behave as intelligent individual agents. Therefore it seems that these examples of guidance techniques can be generalized to the design principle of using agents. The different types of guidance discussed in section 2.3.1 can help structure the selected design principles. In Table 2.1 a short summary of the discussed design principles and guidance types

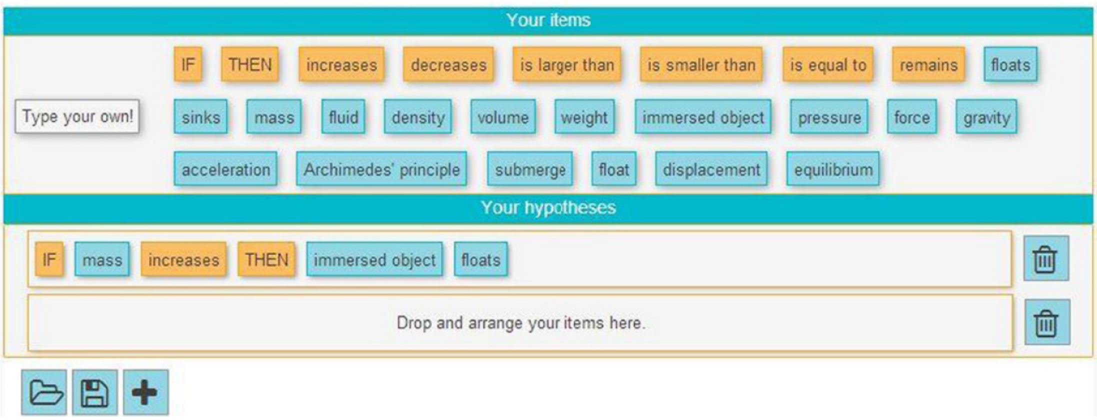


Figure 2.2: The hypothesis scratchpad in Go-Lab (De Jong et al., 2014)

is shown. In this table the (meta)cognitive activity that is supported by the design principle is also listed, just as the inquiry cycle phase in which the design principles can best be applied. Especially the examples of guidance used in the Questioning phase will be useful for this project.

Table 2.1: Summary of guidance techniques

(Meta)Cognitive activity	**Design principle**	**Guidance type**	**Inquiry cycle phase**	**Example**
Organising metacognitive knowledge	Agents	Prompts, Heuristics	All phases	Mr. Davis, Inquiry Island advisors
Reading, Making sense of information	Models	Status overview	Orientation phase	Betty's Brains Model feedback
Task planning	Structuring	Process constraints	All phases	Research Notebook, subtasks in Betty's Brain, tabs in Go-Lab
Integrating knowledge, generating questions, experiments	Choice reduction	Scaffolds	Questioning Phase, Hypothesis Phase, Exploration phase, Experimentation phase	Hypothesis Scratchpad, Questioning Scratchpad, Experiment design tool

Chapter 3

Preliminary research

In chapter 2 the characteristics of a good research question were discussed. Ideally the research questions written by children would have some or even all of these characteristics. The digital tool that will be developed in this project, is meant to guide children, so they can write research questions of this level. In order to determine the manner and amount of guidance the digital tool needs to provide, we first need to know the base level of the research questions children write, in other words what the quality is of the research questions children write without guidance. To this end a preliminary research was conducted with the goal to get a feel for the cognitive level of children and to see what type of research questions they come up with if they receive no guidance.

3.1 Method

3.1.1 Participants

Two 8^{th} grade classes (children in the 8^{th} grade in the Netherlands are generally 11 or 12 years old) from two different elementary schools participated in the preliminary research experiment. 34 pupils participated in total. The participants were divided into groups of about five pupils, which were tested sequentially. Before the experiment started the participants were asked whether they already had some experience with doing (some simple) research, a small number of the participants reported they did already have some experience with doing research.

3.1.2 Materials

To be able to come up with a research question a context is needed. This context can be from society, empirical material, other scientific literature or personal experience (Alvesson & Sandberg, 2013). The subject chosen for this preliminary research experiment is bees, as the data set Naturalis used to test their first prototype of the Nature lab was also on bees. This data set was gathered during a yearly national bee count in the Netherlands, called “Nederland zoemt!”. An infographic displaying several properties of bees was made to provide this context (see Appendix B).

Each participant also received an A4 paper with three lined boxes, where the research questions could be written down. Pens where provided to the participants by the experimenter.

3.1.3 Procedure

At both elementary schools the experiment was held in a quiet room. When a group of about five pupils came in, they were asked to sit around a table with the experimenter. Each participant then received the infographic and the sheet of paper to write the research questions on. Then a group discussion was held for approximately five minutes to introduce the context. During the group discussion the participants were asked what they already knew about bees, this was meant to help bring the knowledge the participants already had about bees to the surface. The infographic was used as a starting point for the discussion.

After the introductory discussion, the participants were asked to write down at least one research question relevant to the topic. The participants were given about ten minutes to accomplish this task, after which some of the research questions they came up with, were discussed in the group. This discussion of the research questions was meant to get insight into the reasoning process of the participants that lead to the research question the participants wrote.

3.2 Results

In total the pupils wrote down 94 research questions. These questions were classified with Bloom's taxonomy (Bloom, 1956) and as research types (Alvesson & Sandberg, 2013) as discussed in section 2.1.2.

Figure 3.1 shows that about 70% of the research questions are on the "Knowledge" level of Bloom's taxonomy. This means that answering these research questions only requires low level cognitive skills.

Figure 3.2 shows the distribution of research questions over the different research types. About 90% of the research questions were related to either descriptive or explanatory research. Only one research question could be classified as belonging to a comparative research type and

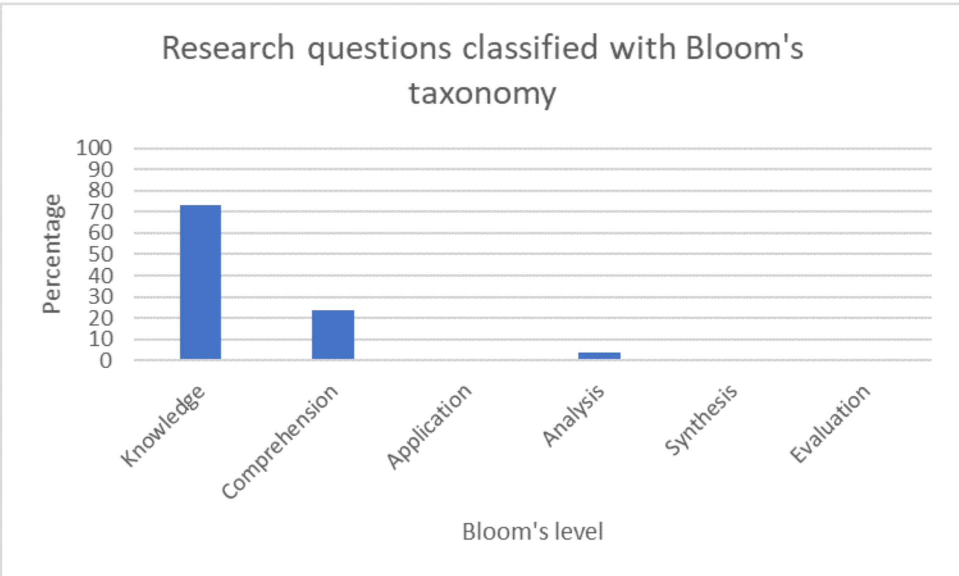


Figure 3.1: Pupils' research questions gathered during the preliminary research experiment, classified with Bloom's taxonomy.

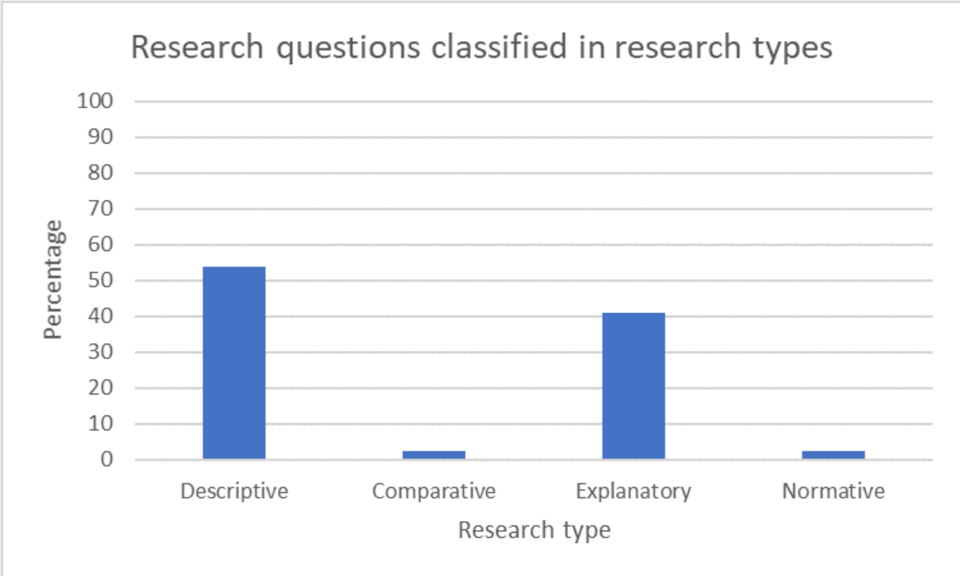


Figure 3.2: Pupils' research questions gathered during the preliminary research experiment, classified as research types.

only one research question could be categorized as belonging to a normative research type.

Finally, we looked at the way the research questions were formulated. Here it became obvious that the pupils had not yet learned how to ask formal questions. This resulted in research questions like: *How often do they go and gather pollen in a day?* where the subject, in this case bees, was only referred to, but not mentioned explicitly. Other pupils were inclined to ask multiple questions at once, such as: *What flower does the honey bee like the most and where does this flower occur most?* not recognising that those questions, even though they were related, were two separate research questions. Finally, some research questions were not specific enough, such as: *How many bees are still alive?* which is basically an impossible question to answer, but also disregards that there should be constraints to which type of bee is meant and what the restrictions to location are (are we including possible bees in space?).

3.3 Discussion

This preliminary research was conducted to determine the base level quality of research questions children write without guidance. The results of this preliminary research show that most research questions children write without guidance are of a low cognitive level and of a low-complexity research type. Furthermore we found that some children have difficulty with formulating a research question in a formal way. Poorly formulated research questions are not a good basis for a research project, as a research question can for example help determine the boundaries of a project. Here there seems to be an opportunity for a guidance tool to support children in the process of writing formal research questions and scaffold them towards research questions of a better quality.

It should however be noted that the group discussion that was meant to provide the context of the experiment, might not have been extensive enough to enable all children to write a good research question. The group discussion was relatively short and might thus not have provided the children with enough opportunities to activate relevant prior knowledge, which could have helped them write a good research question. On the other hand, all children did manage to formulate at least one research question and some did also write more complex research questions, so we conclude that the introductory group discussion was sufficient for the purpose of this experiment.

In conclusion, most research questions were of relatively low quality and could be easily answered by looking up the answers in a book or on the internet, excluding the need for performing an actual research project. As Naturalis wants to engage the children in exploring the available data themselves through doing a research project, the goal is to guide children towards writing a research question of a somewhat higher complexity and cognitive skill level. In chapter 4 we will discuss three paper prototypes designed to accomplish this goal.

Chapter 4

Paper prototypes

The preliminary experiment showed that without guidance children write research questions of relatively low complexity and of a low cognitive skill level. For the children to be able to conduct their own research project with Naturalis' data, research questions of a somewhat higher complexity and cognitive skill level are necessary. Three paper prototypes were designed to guide children towards writing research questions of a better quality. These paper prototypes are inspired by the literature and based on design principles (see Table 2.1). The goal of these design principles is to support the (meta)cognitive activities necessary to perform the task of coming up with and writing a research question. (Meta)cognitive activities in inquiry-based learning were already briefly discussed in chapter 2. Writing a research question involves reading comprehension to make sense of new information on a subject, integrating new knowledge with existing knowledge, using metacognitive knowledge to identify the gaps in the individual's internal knowledge and then using this information to help generate a possible research question. Finally, the child needs (meta)cognitive knowledge about the structure of a research question to be able to write it down. One could argue that the first two activities, reading new information and integrating knowledge, are not part of the Questioning phase, but part of the Orientation phase. While this is probably a more logical classification, we did decide to take those (meta)cognitive activities into consideration as they are an important step in the process of coming up with a research question.

Three paper prototypes were developed. The knowledge-curiosity tool is mainly aimed at providing guidance for the process of coming up with a research question. The literature shows that inquiry-based learning is meant to help fill a knowledge gap (Prince & Felder, 2006) and prior knowledge has an important role in the learning process (Bransford et al., 2000). Moreover, motivated and interested children will learn more easily than unmotivated and uninterested children (Anderson et al., 1998). As such the knowledge-curiosity tool will first explore the prior knowledge and interests of the child, before helping the child to come up with a research question, using this information.

The word-block tool and agent tool are focused on providing guidance for the process of writing a research question. The word-block tool is based on the design principle "Choice reduction". The number of words the children can choose from when writing a research question is reduced to a pre-selected amount.

The agent tool is based on the design principle "Agents". An agent analyses the research question and provides the children with feedback.

In this chapter the design process of the three paper prototypes will be discussed.

4.1 Knowledge-Curiosity tool

The Knowledge-Curiosity tool was inspired by the literature on the importance of curiosity and prior knowledge in learning. The Knowledge-Curiosity tool presents the user with a series of questions to determine their knowledge level on a subject and their specific interests in that area. It is the goal of Naturalis to teach users of the Nature lab about and through science. This learning process will be most efficient if they learn about subjects that are new and interesting to them.

We call the questions that have to determine the knowledge level of a user, fact questions, because they are facts or statements, about a certain subject that have to be answered with "true" or "false". We call the questions that have to determine the interests of the user, curiosity questions. The curiosity questions are a list of subjects from which the user can choose. They should select those subjects that sound most interesting to them. The Knowledge-Curiosity tool will then use this information to suggest a selection of research questions to the user. The user can then decide to explore one of the suggested research questions or to write their own research question, possibly based on the suggested research questions and their own exploration of their knowledge and interests.

As both the fact questions and the curiosity questions are based on the same principle, we chose to only develop the fact questions as a paper prototype to limit the amount of paper needed to make the paper prototype and the time to conduct the paper prototype experiment. The Knowledge-Curiosity tool paper prototype consists of a set of paper cards with on one side a fact question and on the other side two suggested research questions. The subject used for the paper prototype testing is the same subject used during the preliminary research: bees. A form with instructions was also handed to the participants of the experiment (see Appendix C). On this form the participants had to write down the suggested research questions that they found interesting and one final research question.

The flow of the Knowledge-Curiosity tool is illustrated with a swim-lane chart, where the top lane represents the (meta)cognitive activities the user performs when performing the actions represented in the second lane, while the bottom lane shows the processes within the tool (see Figure 4.1). The tool provides the fact question cards, a form with all the answers to the fact questions and the instruction form. The user should first answer all fact questions by marking either "true" or "false" with a pen on the fact question cards, then use the answer form to check their answers and then look at the suggested research questions on the back of the fact question cards that they answered wrongly. The user should choose those research questions that interest them most and then choose one research question from that selection or write their own research question based on the suggestions. The results of this process should be a research question that can be investigated further in the rest of the inquiry cycle.

4.2 Word-block tool

The Word-block tool paper prototype was mainly inspired by the Questioning Scratchpad available through Go-Lab (De Jong et al., 2014). The Questioning Scratchpad, meant to help users formulate a research question, consists of word-blocks that can be dragged and dropped to form a sentence. De Jong et al. (2014) distinguished two word types, namely "conditionals", such as *is smaller than*, and "variables", such as *weight.* Users can also add their own words to the research question if the provided options are not sufficient. By offering the user the (most important) words that are needed to form a research question, the amount of choices the user needs to make when formulating a research question are reduced, thus reducing the cognitive load (Mayer & Moreno, 2003).

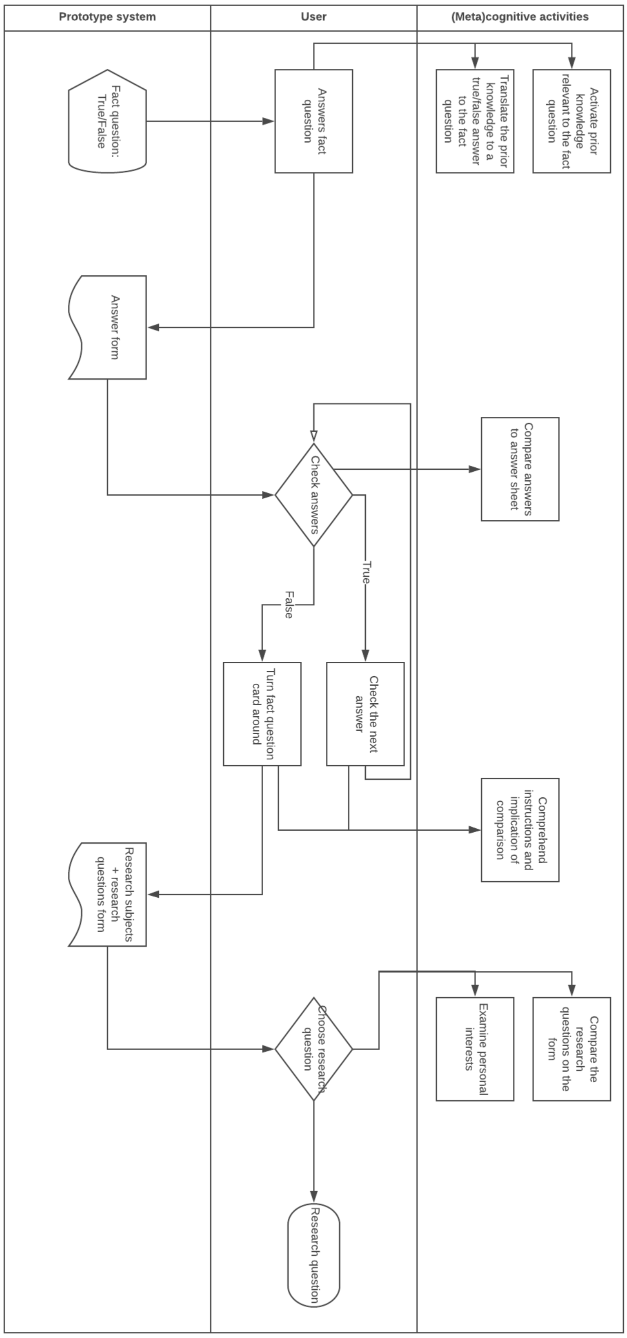
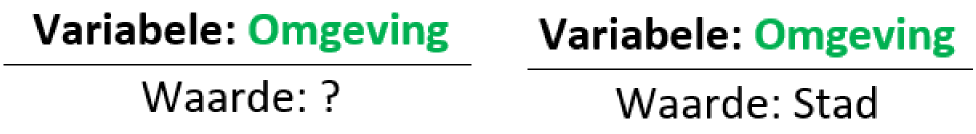


Figure 4.1: Swim-lane chart of the Knowledge-curiosity tool prototype



(a) Variable name word-block (b) Variable value word-block

Figure 4.2: Variable word-block design

The Word-block tool uses the same two word types as the Questioning Scratchpad. However, the Word-block tool divides the "conditionals" of the Questioning Scratchpad into three separate word types: conditionals, such as *smaller than*, filler words, such as *it* and question words, such as *what*. We hypothesize that making this distinction makes it easier for the user to formulate a research question, as the category names better represent their content and are better indicators for their possible placement in a research question. The results from the preliminary research were used to compile a list of frequently used question words, filler words and conditional words (see Appendix D) that were turned into word-blocks. As it is almost impossible to include all words users might want to use in their research question, we also want to offer the user the option to add their own words. This can be done by first creating a new word-block containing the word they want to add and then potentially adding this word-block to the research question.

We used the same subject for all three paper prototype experiments, therefore we based the variables in the "variables" category on the "Nederland zoemt!" dataset. This data set contains the following variables: *Place*, *Environment* and *Bee species*. The *Place* and *Environment* variable have three values each, the *Bee species* variable has 32 values. To not limit the user too much in the kind of questions they could ask, we designed word-blocks with specific variable values and word-blocks with only the variable names, while keeping a consistent design that clearly shows the hierarchy of variables and variable values (see Figure 4.2).

The flow of the Word-block tool is shown in Figure 4.3. The actions the user can perform when interacting with the word-block tool are: picking up a word-block from the table and adding it to the research question they are "writing", returning a word-block to the table and checking if the research question is finished. The corresponding (meta)cognitive activities are again shown in the top lane. The result of this process will be a research question. The processes within the tool are for this prototype limited to offering the word-blocks to the user.

4.3 Agent tool

Our literature study showed multiple examples of the use of agents in inquiry-based learning tools. These agents often have the role of advisors who give hints at appropriate times during the inquiry process, such as Mr. Davis who would for example advice users to re-read resources about certain concepts when Betty answered quiz-questions incorrectly about those concepts (Biswas et al., 2015). The Agent tool prototype makes use of an agent that provides feedback on the research question to the user.

In order for the agent to give useful feedback, the agent should first be "taught" what the requirements of a research question are. In section 2.1.2 we gave a definition of a good research question. From this definition some requirements were extracted to be used by the agent to judge the user's research question. Some other requirements were extracted from Alvesson & Sandberg (2013) and Oost & Markenhof (2010). These requirements together form a checklist the agent

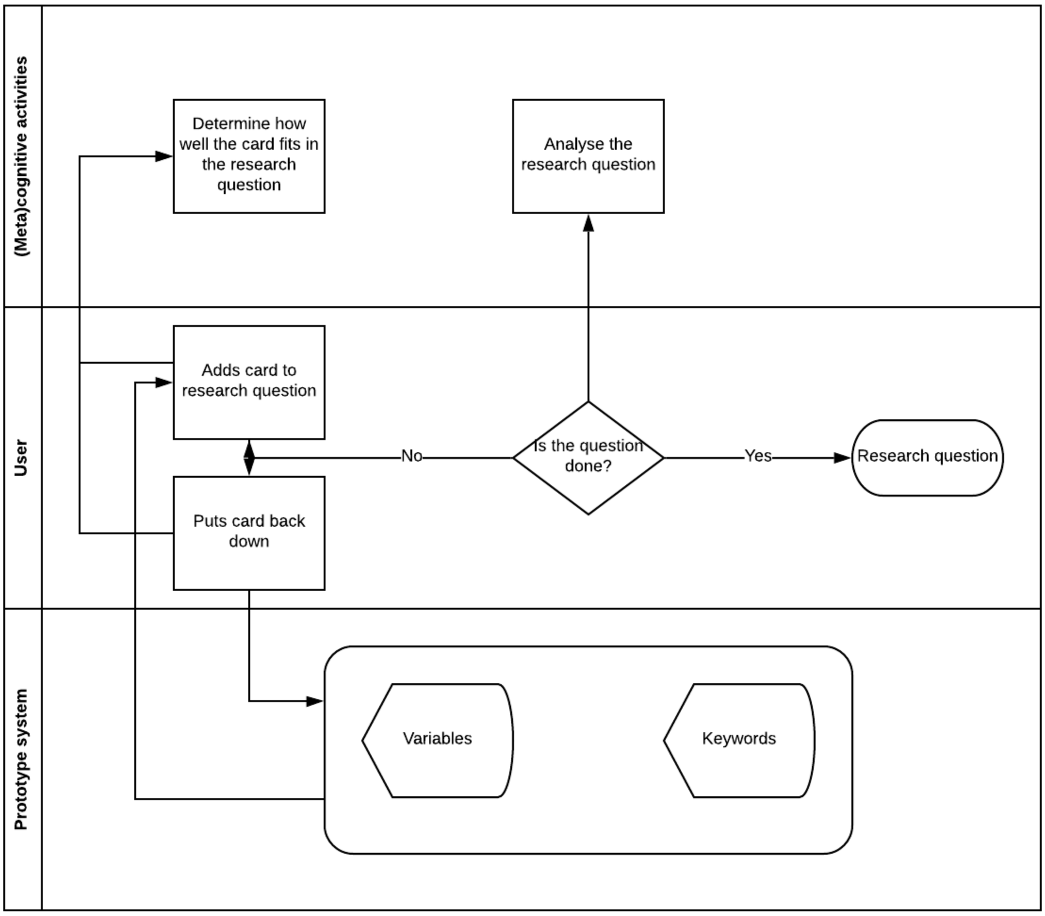


Figure 4.3: Swim-lane chart of the Word-block tool prototype

can use to judge the quality of the research question and give the user insight into the elements their research question might be missing.

Section 2.1.2 stated that different types of research are associated with different types of research questions. As the Nature lab is aimed at high school students and comprises a subject area with a clear boundary, namely the subject area of natural science, the type of research that can be conducted and hence the type of research questions that can be answered, is limited. Furthermore the types of research questions that can be answered within the Nature lab are limited by the available data and available research methods. The requirements included in the checklist were chosen with these limits in mind.

As the prototypes were tested in a Dutch school and Naturalis is developing a Dutch system, the checklist is in Dutch, for this thesis they are translated to English.

- Is the research question associated with the subject “bees”?
- Is the sentence a question?
- Is there a question-word in the sentence?

- Are there one or more variables in the sentence?
- Does the question ask for a comparison between two variables?
- Could the question be answered with a research activity?

As the exact concept of an agent is impossible to test as a paper prototype, we decided to have the participants of our experiment take on the role of the agent for each other, using the checklist. First the participants wrote down a research question on a form (see Appendix E) without the "agents" guidance. Then we asked the participants to write down what they thought would be the answer to their research question and how sure they were of that answer, as Cuccio-Schirripa & Steiner (2000) stated that the answer to a good research question is unknown prior to the actual research. Then each pair of participants swapped their forms and peer-reviewed each others research questions. The requirements in the checklist are formulated as questions to make them easier to check as the participants now only have to answer the requirement question, instead of interpreting a statement and judging whether that requirement is present in the research question. Furthermore examples of the requirements were provided to help the participant understand the requirements better. Each requirement is worth a certain amount of points. If the research question met the requirement the participant should give full points and if the research question only met the requirement partially, half points. The higher the total amount of points, the better the quality of the research question.

Figure 4.4 shows the swim-lane chart for the paper prototype of the Agent tool. The top lane again represents the users (meta)cognitive activities, the second lane the actions of the user, while the bottom lane represents the processes within the tool. The tool offers the form that has to be filled out by the user. The user's first activity is to write down a research question, the peer-reviewer then checks the research question with the checklist and gives it a score. The feedback is returned to the user and the user subsequently uses the feedback to improve their research question if necessary. This feedback loop can be repeated until the user is satisfied with their research question. The corresponding (meta)cognitive activities to the user actions can again be found in the top lane.

4.4 Method

4.4.1 Participants

Each paper prototype was tested with four high school students. All twelve students were in the first class (11-12 years old) of the Kamerlingh Onnes school in Groningen and were either at the HAVO or VWO level. Due to time constraints all participants were tested at the same time. The participants received licorice as a reward at the end of the experiment.

4.4.2 Materials

For the paper prototype testing the subject used was again bees. Just as in the preliminary research the participants received a short introduction to provide them with context, before testing the paper prototypes. For the introduction we used a piece of paper, a pen to draw on the paper and coloured licorice, to help explain the concept of variables.

For the paper prototype testing all participants received a pen from the experimenter. The participants testing the Knowledge tool also received an instruction form, the fact question cards and finally a form with the answers to the fact questions (see Appendix C). The instruction

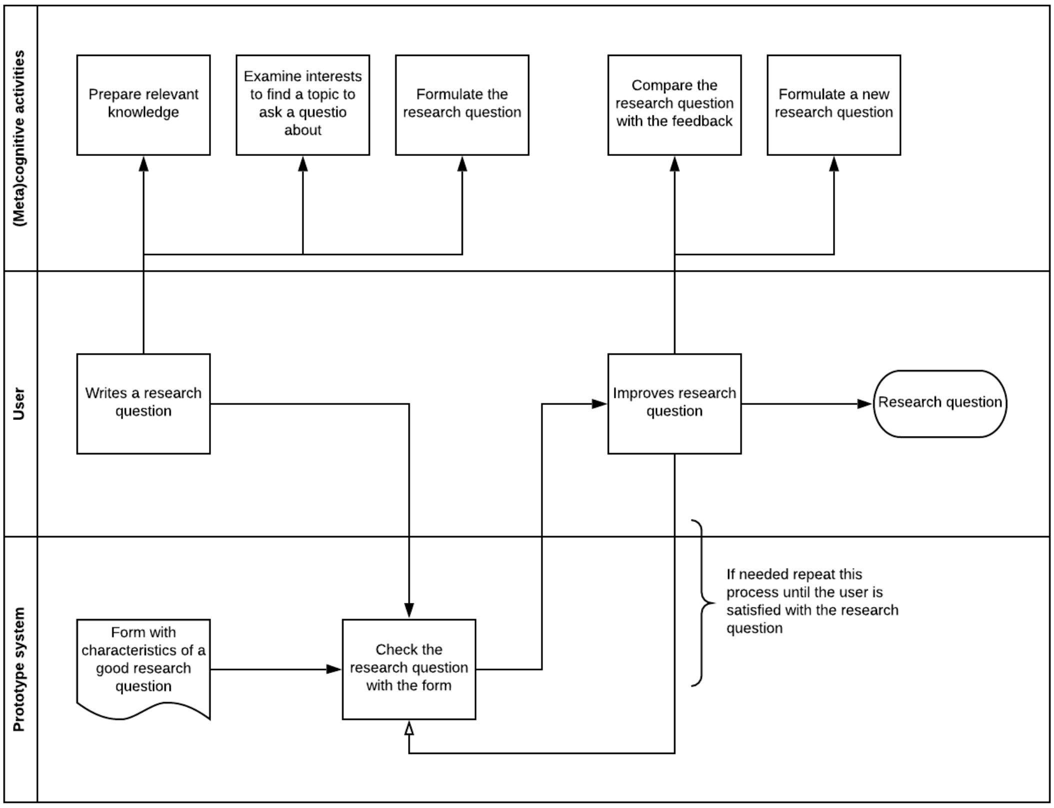


Figure 4.4: Swim-lane chart of the Agent tool prototype

form also contained a lined section where the participants could write down their own research question(s).

The participants testing the Word-block tool each received a set of word-blocks and a blank paper to write down their research question(s) on.

The participants testing the Agent tool received a question form, with room to write the answer to the questions down, and a checklist containing the characteristics of a good research question (see Appendix E). The checklist also contained a column for the peer-reviewer to note down the score on each characteristic.

At the end of the experiment the participants filled out a questionnaire that asked them eight questions about how they experienced working with the paper prototype. These questions were grouped under three evaluation types as follows:

- Usability
  1. I understood how to use the guidance tool.
  2. I found the guidance tool easy to use.
  3. I understood how to use the guidance tool quickly.
- Instructiveness

4. The guidance tool helped me to understand the process of formulating a research question.
5. The guidance tool helped me understand what a good research question is.

- Usefulness

6. I found the guidance tool useful.
7. With the guidance tool I was able to write a better research question than I could have done without it.
8. I would use such a guidance tool more often when formulating research questions.

4.4.3 Procedure

All three groups received a general introduction on the subject of bees together. To introduce the concept of variables, the variables *Environment* and *Place* were drawn out as labeled circles on paper. The licorice was used to illustrate different species of bees that occupied a certain environment and place on the paper. The participants were given two examples of possible research questions using the drawn-out example and they were made aware of the importance of a good research question when doing research.

After the general introduction each group of participants received a more specific explanation of the paper prototype they would be testing. For the Knowledge tool the participants were first provided with the fact question cards and the instruction form. They were instructed to first read the instructions and then answer the fact question accordingly. They were instructed to notify the experimenter when they were done with this part of the experiment, they would then receive the answer key to the fact questions and could follow the rest of the instructions on the instruction form.

For the Word-block tool the participants received the set of word-block cards and a piece of paper to write their research question on at the start of the experiment. The participants were informed they had to write a research question using the word-blocks, that they were allowed to use all word-blocks as they wanted and that they could add their own words on the blank word-blocks that were also provided.

For the Agent tool the participants first received the question form and they were instructed to write down their own research question and come up with a possible answer to their research question. They were then instructed to inform the experimenter if they were done with this part. When notified the experimenter provided the participants of this group with the checklist and instructed the participants to swap their question form with their neighbour. The experimenter then explained how the participants should use the checklist. The participants were instructed that they could always ask questions during the experiment if something was unclear.

The groups were then given 15 minutes to work with the paper prototypes with as end goal to produce their own research question(s). After the participants were done with the paper prototype experiment they were asked to fill out the questionnaire. Finally, an open unstructured group discussion with all twelve participants was held to hear their opinions on the paper prototypes.

4.5 Results

The four participants using the Knowledge tool prototype wrote down six research questions in total. The four participants using the Word-block tool paper prototype wrote down seven

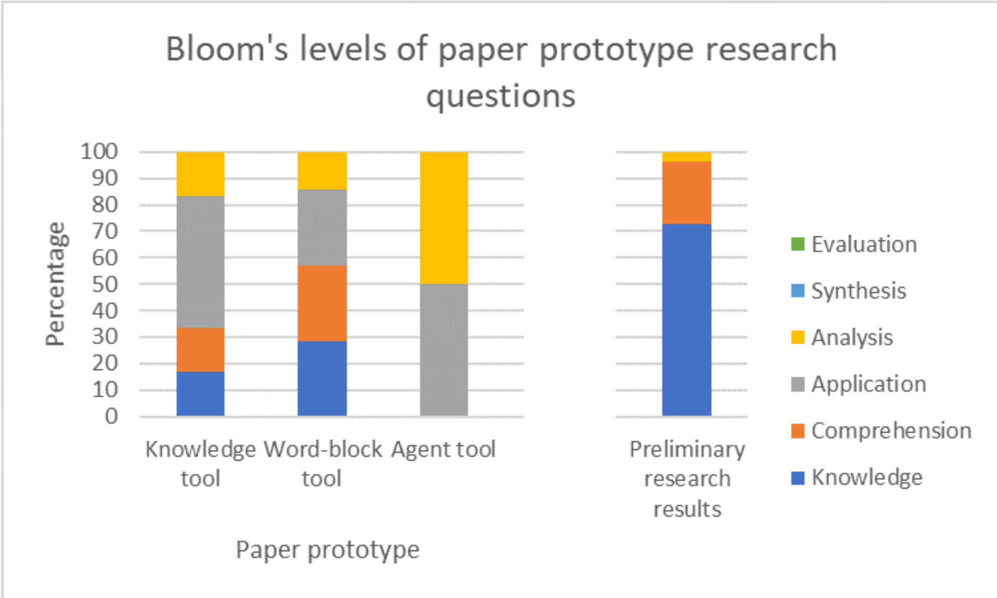


Figure 4.5: Classification of the participants' research questions per prototype in Bloom's taxonomy, with the preliminary research results to the right for comparison.

research questions in total. The four participants using the Agent tool paper prototype each wrote one research question, but only two participants used the feedback to improve their research question, To analyse the research questions produced with the guidance of the paper prototypes, we applied the same methods used to analyse the results of the preliminary research.

Figure 4.5 shows the Bloom's levels of the research questions written with the paper prototypes and the results from the preliminary research. The research questions written with the Knowledge tool are mostly on the "Application" level. We see a pretty even distribution of research questions over four Bloom's levels for the Word-block tool and the research questions written with the Agent tool are evenly divided over two bloom's levels.

Figure 4.6 shows what type of research questions were asked by the participants using the paper prototypes. The research questions written with the Knowledge tool and the Word-block tool show a similar distribution with most research questions of a comparative research type. All research questions written with the Agent tool were of a explanatory research type.

Note that the proportions in Figure 4.5 and Figure 4.6 are in percentages as the participant groups did not produce an equal number of research questions. Two of the four research questions produced with the Agent tool were excluded from analysis as those were not improved based on the feedback and the participants did thus not use the paper prototype correctly.

Comparing the results from the paper prototype testing to the results of the preliminary research, we see that the research questions written with the guidance of the paper prototypes are on average of a better quality than the research questions written without guidance during the preliminary research.

We were also interested in the differences between the paper prototypes, as we want to know how they compare. Looking at the Bloom's levels we see that the Word-block tool produced research questions of a lower cognitive level than the other two paper prototypes. Overall the Agent tool resulted in research questions of the highest cognitive levels. The Agent tool is also the tool that resulted in research questions of a high complexity research type, while the

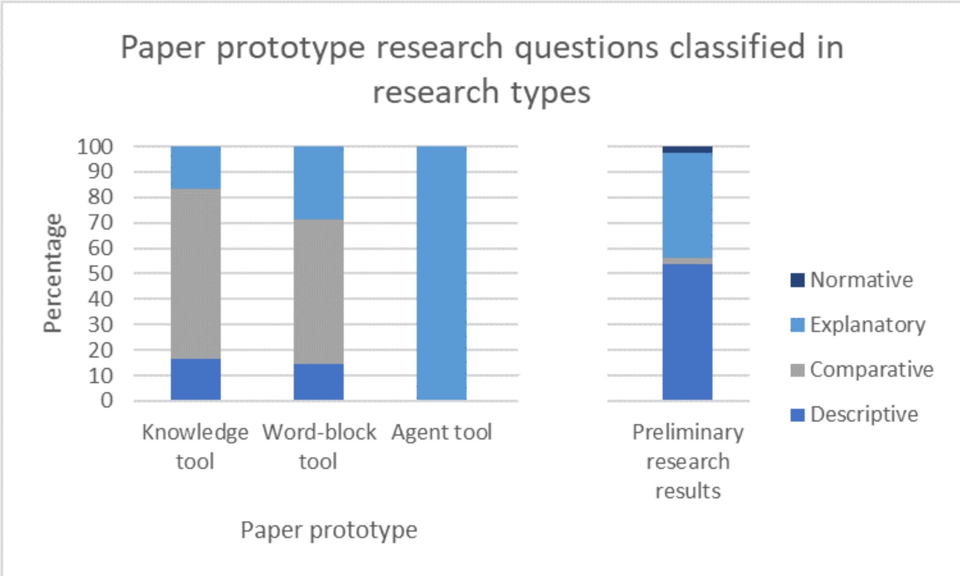


Figure 4.6: Classification of participants' research questions, per prototype, in research types, with the preliminary research results to the right for comparison.

Knowledge tool and Word-block tool gave very similar results. Table 4.1 shows the results of the questionnaire per paper prototype. Participants rated the eight questions on a 5 point likert-scale. Where 1 meant strongly disagree and 5 meant strongly agree. The mean scores for each evaluation type was calculated and is shown in the table. The results show that the participants were mostly positive about the paper prototypes. All evaluation types were scored above the neutral 3. Noteworthy is the score below 4 for the usability of the Knowledge tool. In section 4.6 we will speculate about why this is.

4.6 Discussion

We designed three paper prototypes and tested each on four participants. The goal of this thesis is to design a guidance tool that can help children formulate research questions of a better quality within inquiry-based learning. With this experiment we tested three guidance tool paper prototypes, with the goal of finding out whether the paper prototypes had an effect on the quality of the research questions children write and if so, which paper prototype worked better. In order to determine this, the research questions the participants produced with the paper prototypes were analysed and the Bloom's level and associated research types were compared.

The results of the paper prototype testing showed that the prototypes seemed to have a positive effect on the cognitive level of the research questions the students produced and that the type of research questions were more complex than the types of research questions written during the preliminary research. We should note however that there is an age difference between the participants in the preliminary research and the participants of the paper prototype testing. The preliminary research was tested with eight grade elementary school students, at the end of the school year. The paper prototype testing was done with first-year high school students on the HAVO/VWO level, at the start of the school year. This means the age difference is not very large, which is why we did make a comparison between the results of the preliminary research

Table 4.1: Questionnaire results for all three paper prototypes. P1 = Knowledge tool, P2 = Word-block tool, P3 = Agent tool

	Question	Average Score P1	Average Score P2	Average Score P3
Usability	1. I understood how to use the guidance tool	3.75	4.6	4.3
	2. I found the guidance tool easy to use			
	3. I understood how to use the guidance tool quickly			
Instructiveness	4. The guidance tool helped me to understand the process of formulating a research question	4.4	4.1	4.1
	5. The guidance tool helped me understand what a good research question is			
Usefulness	6. I found the guidance tool useful	4.3	4.2	4.2
	7. With the guidance tool I was able to write a better research question that I could have done without it			
	8. I would use such a guidance tool more often when formulating research questions			

and the paper prototype testing. However, in the eight grade of elementary school the students have not yet been selected for the different education levels of high school, which might have influenced our observed results, meaning we can not rely too heavily on the comparison we made.

When comparing the paper prototypes it appears that on average the Word-block tool produced research questions that were more on the "Knowledge" level of Bloom's taxonomy. This kind of research question can generally be answered by looking up the answer in the literature. As the aim of the Nature lab is to encourage children to explore the available data themselves, research questions of a somewhat higher cognitive level are necessary. The classification of the research questions in research types did not show any clear differences between the Knowledge-Curiosity tool and the Word-block tool, but the use of the Agent tool resulted in research questions of a better quality than the research questions written with the other two tools. Moreover, to allow the student to write a good research question with the Word-block tool the number of options that has to be provided becomes so large, it becomes too time consuming to go through all the options. Providing fewer pre-made word-blocks and depending on the students to use the blank word-blocks to complete the research question, takes away from the advantage, fewer choices to make, the Word-block tool has over the other two prototypes. Taking these results together we can conclude that guidance through the Agent tool or the Knowledge-Curiosity tool might be preferable.

The results from the questionnaire showed that on average the students were positive about the usability, instructiveness and usefulness of the paper prototypes. Only the usability of the Knowledge tool was scored below 4. This might be due to the fact that the fact question cards were hard to keep organised, resulting in a mess on the table. This score might also be explained by a remark made by one of the participants during the open unstructured group discussion. This participant remarked that it was hard to come up with their own research question, after having read all the suggested research question. The usability of the Knowledge tool was overall rated as positive, so the questionnaire results should not be a reason to drop this prototype from consideration when designing the digital prototype.

Another goal of the experiment was to observe whether the participants used the tools as intended. For the Word-block tool we observed that some participants created their own word-block for the word “bees”, while they could also have used the provided variable card. So it appears it was not clear to the participants how to use the variable cards in a sentence.

For the Agent tool we observed that two participants did not use the feedback provided to them with the filled out checklist to improve their research question. This suggests that it was either unclear they had to improve their question or that they did not know how to use the feedback to improve their question. Especially the latter is an important point to take into consideration when designing the digital tool.

For the Knowledge-Curiosity tool we observed that participants did not only look at the suggestions from the cards they had answered incorrectly, but at the suggestions on all cards that were provided to them. This is easily solved in a digital environment as it can be controlled what a user gets to see after answering the fact questions.

In conclusion the paper prototypes seemed (on average) to have a positive effect on the quality of the research questions. The participants were mostly positive about all paper prototypes, with no clear difference between the appreciation of the paper prototypes. A difference was found in the quality of the research questions produced with the paper prototypes, where the research questions written with the Agent tool were of a better quality than the research questions produced with the Knowledge-Curiosity tool and the Word-block tool. As the Knowledge-Curiosity tool supports different cognitive activities than the other two tools, it might be interesting to explore the possibility of combining the Knowledge-Curiosity tool and the Agent tool when designing the digital prototype.

Chapter 5

Digital prototype: Bijennatuurlab

5.1 Introduction

In chapter 4 three paper prototypes were described. These paper prototypes were tested on a small scale and the results were reported and discussed. Overall the paper prototypes seemed to have a positive effect on the quality of the research questions the high-school students produced. The paper prototypes were overall positively received. A difference was found in the quality of the research questions produced with the paper prototypes, where research questions written with the Word-block tool were of a low cognitive level and of a less complex research type compared to the other two paper prototypes. There was however not an obvious difference in appreciation for the paper prototypes. After analysis of the result of the paper prototype testing, it was decided to only make a digital version of the Knowledge-Curiosity tool and the Agent tool.

This chapter will discuss the implementation of the digital prototype and will describe the experiment in which the digital prototype was tested. The results of the experiment will be reported and finally we draw a conclusion based on those results.

5.1.1 Goal of the digital prototype testing

A digital prototype in the form of a website, called *Bijennatuurlab*, was constructed in order to test the digital Knowledge-Curiosity tool and the digital Agent tool. After implementation the digital prototype was tested in order to see which tool resulted in students producing the best quality research questions.

The experiment had a between-subject design. There were two conditions, the Agent condition and the Knowledge-Curiosity-Agent (KCA) condition. In the Agent condition the participants received guidance from the Agent tool twice. In the KCA condition the participants first received guidance from the Knowledge-Curiosity tool and then from the Agent tool. The reverse order, first the Agent tool and then the Knowledge-Curiosity tool, was not tested, as the purpose of the Knowledge-Curiosity tool is to help the user think of a research question. Coming up with a research question comes before actually writing it, therefore it would not be logical to put the Knowledge-Curiosity tool after the Agent tool. In both conditions the participants had to write a research question without guidance before using the tools, so in total all participants wrote three research questions, the *baseline* research question, the *second* research question and the *final* research question. This experiment design is shown in Figure 5.1.

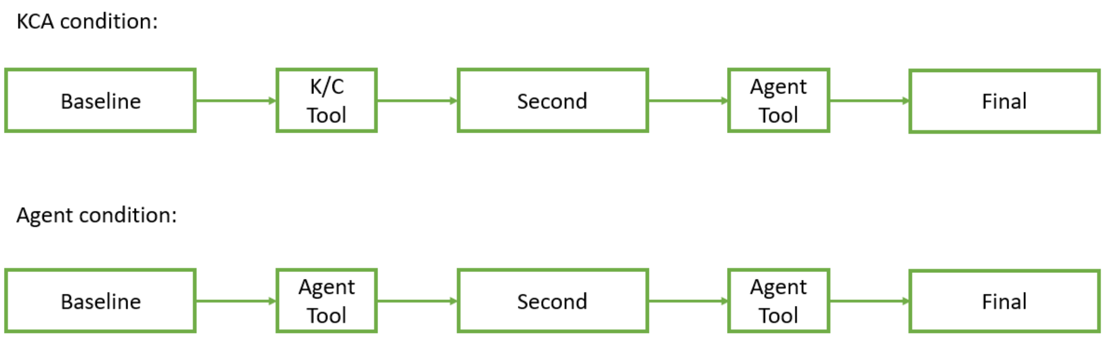


Figure 5.1: Schematic overview of the experiment design

5.2 Digital prototype development

5.2.1 Adapting the paper prototypes

The prototypes of the Knowledge-Curiosity tool and the Agent tool were adapted based on the findings in the paper prototype testing and to make them suitable as a digital prototype.

The paper prototype of the Knowledge-Curiosity tool suggested complete research questions to the user. These research questions were meant to serve as an example to help the user come up with their own research question. This proved to be difficult however, as users struggled to come up with their own new research question. Therefore it was decided that the digital prototype of the Knowledge-Curiosity tool would not suggest complete research questions, but would suggest possible subjects to help the user find a direction for their own research question.

The paper prototype of the Agent tool made use of peer-reviewing, as the concept of an actual agent was impossible to test as a paper prototype. For the digital prototype of the Agent tool an agent was developed to take the place of the peer-reviewer. Furthermore, automatic recognition and highlighting of relevant keywords in the research question written by the user were added.

5.2.2 Bijennatuurlab

The digital prototype was implemented as a website, because this allowed for easy testing with large groups at once, without the trouble of having to install software on school computers. Additionally the prototype of the Nature lab being developed by Naturalis is also a website, so implementing the digital prototype as a website, will allow for easy translation from the digital prototype to their Nature lab if necessary.

The website was scripted in HTML5 and CSS, making use of JavaScript to make the website interactive. Node.js was chosen to construct the server-side of this website. The website was hosted at a server of the University of Groningen.

First five pages of Bijennatuurlab

On the first page of Bijennatuurlab the agent, represented by the picture of a bee, greeted the user and "told" the user what they could expect. The user could then press the "Start" button when they were ready to continue. On the second page the user was required to fill out their subject number, this subject number determined what condition the user got to see. After entering the subject number the user got to see the third page with more detailed instructions for that condition. The fourth page was the same for all users and was the page where they had to fill out some demographics.

This page was followed by the fifth page where the user had to write a research question without guidance (See Figure 5.2). This was the baseline research question. The user could change this research question as often as they liked, until they pressed the "Next" button.

Depending on the condition the user was in, they then got to see the Knowledge-Curiosity tool or the Agent tool.

Digital Knowledge-Curiosity tool

The Knowledge-Curiosity tool consisted of two parts: a knowledge test and a curiosity test. The knowledge test consisted of a list of ten fact questions. These questions were composed in collaboration with Naturalis. Each question was linked to a subject description that related to the subject of the question. When a question was answered incorrectly, this related subject was shown to the user as a suggestion to base a research question on (See Figure 5.3).

The curiosity test consisted of a list of five subjects the user might have found interesting, phrased in such a way that the user was stimulated to think about what they found interesting (See Figure 5.4). The subjects were prompted with the sentence: *I am curious about...* at the top of the list. When the user confirmed their selection, the chosen subjects were shown in the same column as the results of the knowledge test. The last screen of the Knowledge-Curiosity tool prompts the user to write a research question based on the gathered list of subjects and interests.

Digital Agent tool

The Agent tool consisted of three parts. One part showed the characteristics of a good research question in a column. These characteristics were clickable and showed more detailed information on that characteristic in a modal window overlaying the entire page. This part of the Agent tool was meant to teach the user what characteristics a good research question contained and was meant to help structure the user's research question.

The second part contained the text box in which the user could write their research question. If the "Check" button was clicked, the JavaScript took care of analysing the question. The JavaScript first transformed the research question, the input string, to all lower case, in order to make the comparison with certain keywords easier. Then the input string was tokenized, creating a new token for each word or punctuation mark. Then this tokenized list was compared with three types of keywords. These three types of keywords were:

- Words that indicate that a sentence is a question
- Words that could be a variable
- Words that indicate a comparison

Each time a token was matched with a keyword, the corresponding word in the input string was turned to italics and bold. Once the whole sentence had been "scanned" this way, the resulting string was printed to a HTML-tag underneath the text box (See the right side of Figure 5.5 for an example). The words printed in italics and bold showed the user what words were important to the structure of a research question.

The keywords listed above correspond with three of the characteristics shown on the left in Figure 5.5. These characteristics are: *"Is the sentence a question?", "Does the sentence contain one or more variables?" and "Does the sentence ask for a comparison between two variables?".*

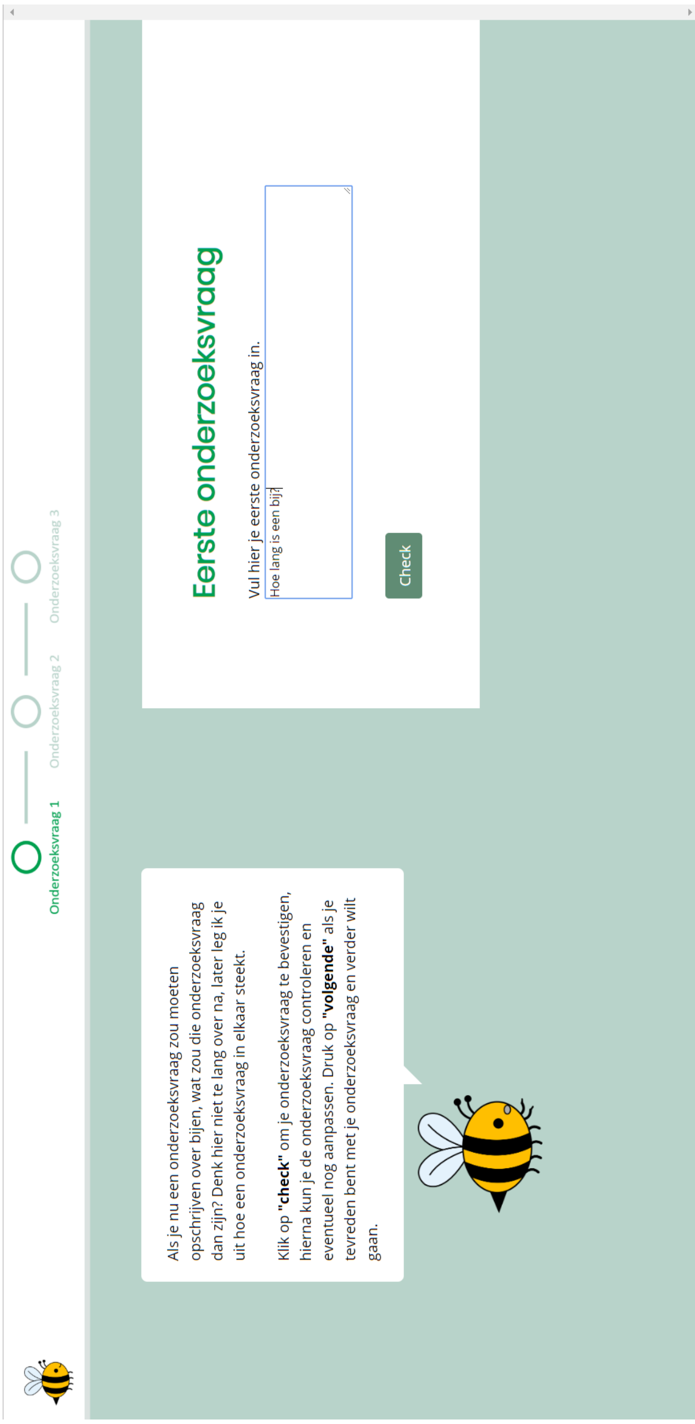


Figure 5.2: Screen capture of the web page on which the user had to fill in a baseline research question without guidance. The baseline research question was to be written in the text box on the right, instructions were provided through the speech bubble on the left.

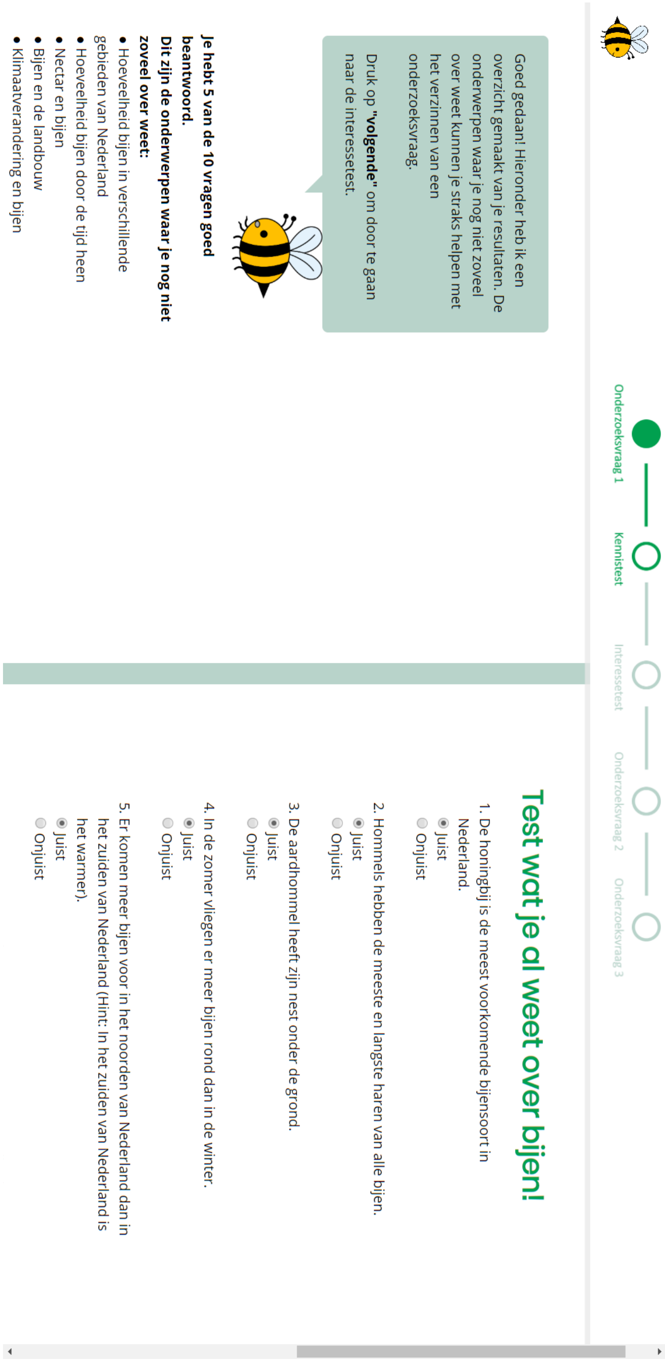


Figure 5.3: Screen capture of the Knowledge-Curiosity tool after submitting the answers of the knowledge test. On the left side the related subjects are shown, together with instructions to the user in the speech bubble. The right side shows the fact questions. The “Next” button is at the bottom of this page.

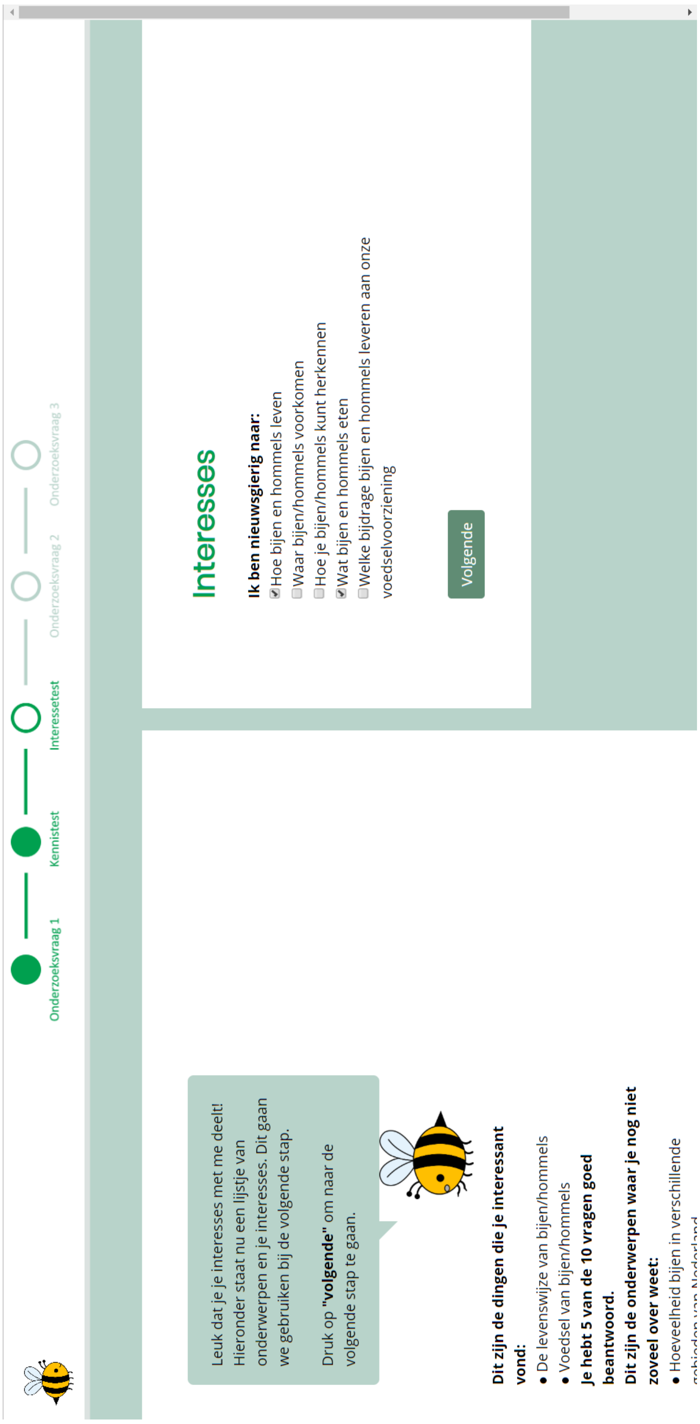


Figure 5.4: Screen capture of the Knowledge-Curiosity tool after submitting the answers of the curiosity test. On the left side the subjects picked by the user are shown together with the results from the knowledge test. The speech bubble contains instructions to the user. On the right side the list of five subjects is shown.

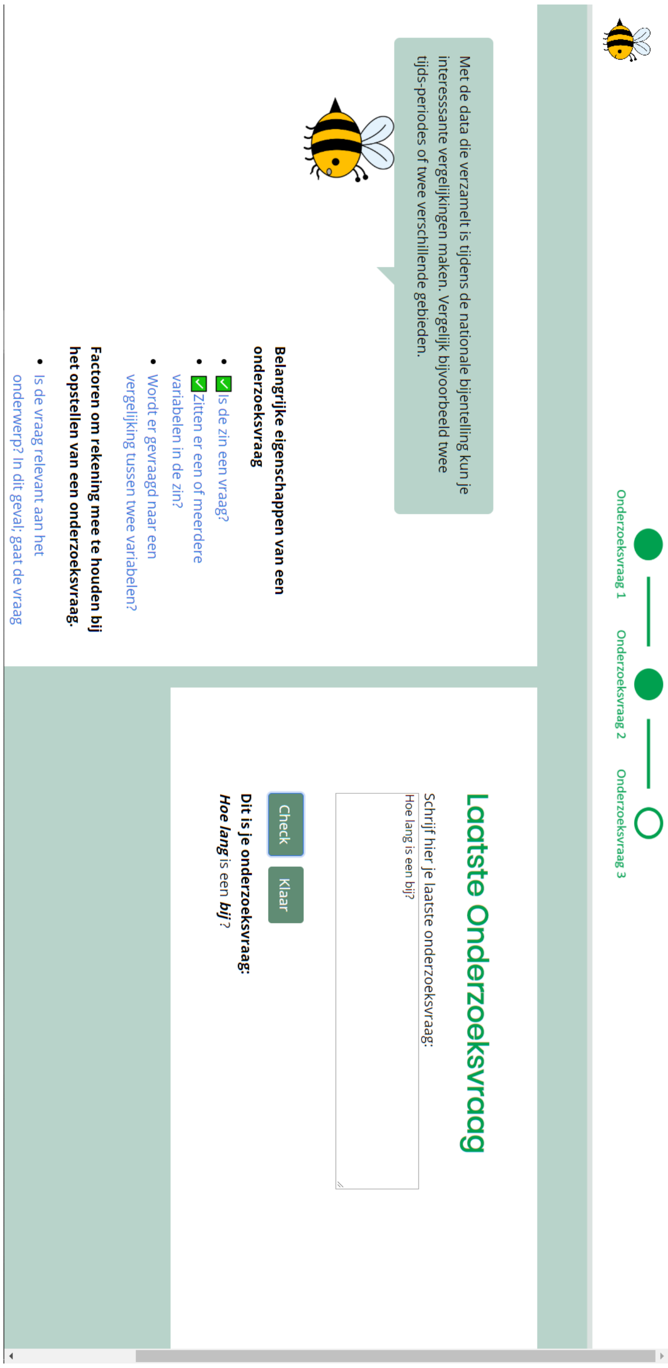


Figure 5.5: Screen capture of the Agent tool after submitting a research question. On the right side a list of characteristics of research questions is shown. Above that list, the agent provides the feedback on the research question to the user. The left side of the page contains a text box in which the user has to write their research question. Beneath the text box the results of the analysis of the research question are displayed.

If a match between a keyword and a token was found, the corresponding characteristic received a green check-mark to indicate this characteristic was present in the research question written by the user.

The third part of the agent tool contained the agent giving verbal feedback to the user in a speech balloon, based on the analysis of the research question by the JavaScript described above. Note that although the bee figure and speech balloons were also used in the Knowledge-Curiosity tool, the purpose of the speech balloons was different here. In the Knowledge-Curiosity tool the speech balloons only contained instructions that were the same for all users. In the Agent tool the speech balloons were used by the agent to give feedback to the user on their research question. This feedback depended on the research question and is thus not the same for all users.

Last page of Bijennatuurlab

The final page of Bijennatuurlab informed the user that they were done with the experiment and contained a link to a page showing the correct answers to the knowledge test and a link to a questionnaire. When the user finished with Bijennatuurlab their data was saved to a csv file.

5.3 Digital prototype testing

5.3.1 Participants

40 high school students participated in this study. Their mean age was 12 years old. All students were in the first year of their studies at the VWO level and attended Kamerlingh Onnes high school in Groningen. The students' participation was instead of their normal Biology lesson. Their teachers agreed to the students' participation by signing an informed consent form, which also stated that all data would be stored anonymously.

5.3.2 Materials

To conduct this experiment each participant needed a computer that had a connection with the internet and a browser installed. The link to the Bijennatuurlab and the subject number were printed on slips of paper.

An introductory lesson was used to establish a context for using the Bijennatuurlab. For this lesson a Powerpoint presentation, made by a researcher at Naturalis, was used. This lesson was aimed at emphasizing the importance of bees for the economy but also their impact on nature. The lesson finished with the participants doing a small exercise in which they had to write down characteristics of some bumblebees species. They then had to use these characteristics to recognize the bumblebee species from a picture or video

At the end of the experiment participants filled out a questionnaire, this questionnaire was a Google survey and consisted of eight questions about the Bijennatuurlab. These questions were grouped under three evaluation types as follows:

- Usability
    1. I understood how to use the guidance tool.
    2. I found the guidance tool easy to use.
    3. I understood how to use the guidance tool quickly.
- Instructiveness

4. The guidance tool helped me to understand the process of formulating a research question.
5. The guidance tool helped me understand what a good research question is.

- Usefulness

6. I found the guidance tool useful.
7. With the guidance tool I was able to write a better research question than I could have done without it.
8. I would use such a guidance tool more often when formulating research questions.

These are the same questions that were used with the paper prototype testing.

5.3.3 Procedure

When participants came into the classroom they were instructed to take a seat at a computer, but to not yet turn the computer on. The experiment then started with the short introductory lesson on bees. This lesson took about 20 minutes.

The participants were then instructed to start the computer and open their browser and open an incognito window. This was to prevent the possible mix-up of subject numbers with other saved form data in the browser. The experimenter then made a round through the class to let every participant pick a slip of paper with the subject number and website link randomly from a small container. This way participants were divided into two groups, the group of participants with an even subject number, were in the Agent condition. Participants with an odd subject number were in the KCA condition. Then the experimenter asked the participants whether they all knew what a research question was and what variables were. If the answer was no, this was explained. The participants then got an explanation of the Bijennatuurlab. Most of the Bijennatuurlab was assumed to be self-explanatory, but the following things were emphasized:

- The goal of the Bijennatuurlab is to practice with writing research questions; There are no good or bad answers
- The research questions can be changed as often as you like before submission
- The green check marks are to show that a characteristic is present, you do not need to have green check marks for each characteristic to have a good question
- The agent does not know everything, so if they do not recognize characteristics in a research question, it does not mean the research question is wrong!
- The Bijennatuurlab is meant to be used *individually*
- Asking questions is always allowed

The participants then were instructed to go to the website and follow the instructions and steps there. The participants had 15 minutes to complete the Bijennatuurlab. A pilot study had shown that this was enough time to finish all the steps in the Bijennatuurlab.

5.3.4 Design

This experiment had a between-subject design with two conditions, the KCA condition and the Agent condition. The dependent variable was the quality of the research questions. The independent variable was the sort of guidance tool used.

5.3.5 Measures and data analysis

During the experiment five types of data were gathered: demographic data collected from the participants, the results of the knowledge and curiosity tests, the three research questions generated by each participant, the number of times the "check" buttons were used and the answers to the questionnaire.

The demographic data collected from the participants were:

- Their previous experience with doing "research"
- If they think they already know a lot about bees
- Level of education
- Gender
- Date of birth
- The place where they went to elementary school
- The name of their elementary school

The main aim of this experiment was to see if the tools, the Agent tool and the Knowledge-Curiosity tool, had an effect on the quality of the produced research questions, therefore we did a within-subject analysis. Furthermore we wanted to compare the effect of the two tools to each other, therefore we did a between-subject analysis (see Figure 5.6). In order to be able to analyse the effect of the Knowledge-Curiosity tool and the Agent tool, these research questions were classified with Bloom's taxonomy and classified as one of the four research types. Both classifications were independently made by three researchers. Any differences were resolved by looking at the majority vote, any remaining differences were resolved by the first author of this thesis.

To make the research questions easier to statistically analyse, the Bloom's levels and research types were transformed to numerical scores. For both classification methods, the "lowest" level, so the Knowledge level for Bloom's taxonomy and the Descriptive research type for the research types, was set to be equivalent to a score of 1 point. One level above that was 2 points and so on. These two scores were then summed to get one total score for each research question.

To perform a statistical analysis of the effect of the tools on the quality of the research questions we compared the baseline research questions, second research questions and final research questions. Since these were repeated measures we used, assuming non-normality, two non-parametric Friedman tests of differences.

To perform a statistical analysis of the tool comparison we compared the three research questions between conditions. As the two groups participating in the two conditions were independent, we used, assuming non-normality, three Wilcoxon rank-sum tests.

To analyse the questionnaire we calculated the mean score for each evaluation type.

5.4 Results

There were 22 participants in the Agent condition and 18 participants in the KCA condition.

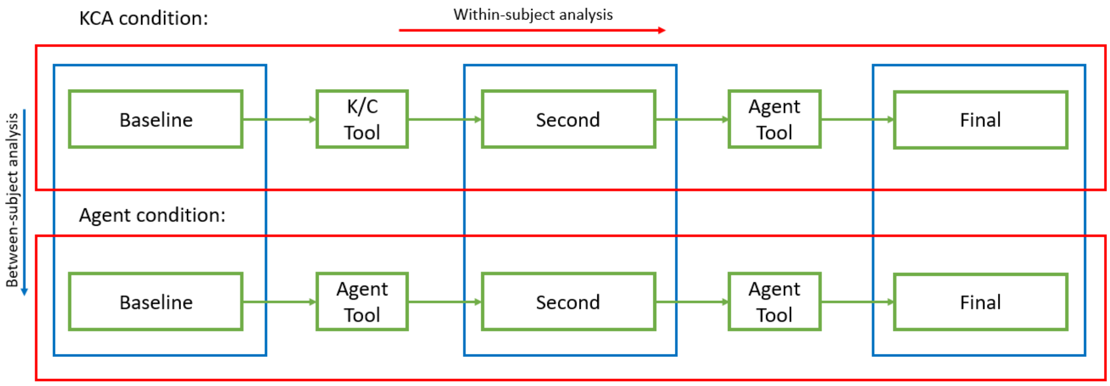


Figure 5.6: Analysis plan. The within-subject analysis is shown in the red box, the baseline, second and final research questions within a condition are compared. The between-subject analysis is shown in the blue boxes. The baseline research questions are compared between conditions, the same for the other two research question types.

5.4.1 Demographics

Each participant filled out the demographics listed in section 5.3.5. As each demographics field was mandatory to fill out, there was no missing data. However, there were two participants who filled in an incorrect date of birth, as it is not possible those participants were born in 2019 and the default date of birth was the current date. When calculating the mean age reported in section 5.3.1 (12 years), these two data points were excluded.

A majority of the participants (26 out of 40) said they already had some experience with doing "research". A minority of the participants (10 out of 40) said they thought they already had quite a significant amount of knowledge about the topic of bees. At most four participants came from the same elementary school; all participants except one were from an elementary school in the province Groningen.

5.4.2 Knowledge and curiosity tests

All participants in the KCA condition made the knowledge and curiosity tests. The website enforced the user to answer all fact questions in the knowledge test and to choose at least one topic in the curiosity test.

On average the participants answered 66.7% of the questions in the knowledge test correctly.

In Table 5.1 the frequency with which each curiosity topic was chosen is shown. The topics "What bees and bumblebees eat" and "What bees and bumblebees contribute to the food supply" were chosen most often. All topics were chosen at least once.

5.4.3 Quality of the research questions

As explained in section 5.1.1 each participant wrote three research questions during the experiment. One participant in the agent condition wrote research questions that were not on topic, the research questions written by this participant were excluded from further analysis.

Table 5.1: Frequency of curiosity topics chosen by participants in the KCA condition

Curiosity topic	**Frequency**
How bees and bumblebees live	4
Where bees/bumblebees can be found	4
How to recognize bees/bumblebees	4
What bees and bumblebees eat	7
What bees and bumblebees contribute to the food supply	8

Effect of the tools

To look at the effect of each tool, we compare the baseline research questions, the second research questions and the final research questions with each other for each condition.

Classification with Bloom's taxonomy Figure 5.7a shows the classification of all research questions generated in the KCA condition in Bloom's levels. From the baseline research questions to the second research questions, there is a shift away from the "Knowledge" level and towards higher cognitive levels. However, from the second to the final research questions we see again an increased proportion of research questions at the "Knowledge" level.

Figure 5.7b shows the classification of all research questions generated in the agent condition in Bloom's levels. There is a decreased proportion of research questions at the "Knowledge" level and an increased proportion of research questions at the "Comprehension", "Analysis" and the "Synthesis" level.

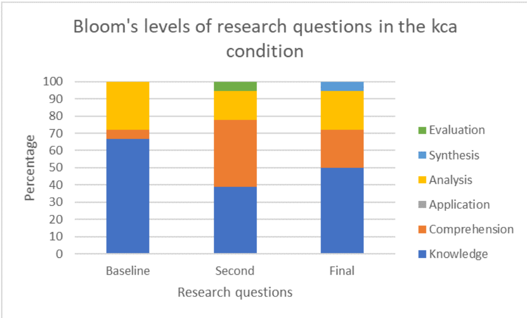
In both conditions the distribution of cognitive levels of the research questions is increased from a concentration at the "Knowledge" level to a bigger spread across lower and higher cognitive levels. In the agent condition this spread continues from the baseline, to the second to the final research question, while for the KCA condition the amount of research questions at the "Knowledge" level decreases from the baseline to the second research question, but increases again from the second to the final research question (when the agent tool provides guidance).

Classification as research type Figure 5.8a shows the classification of all research questions generated in the KCA condition as one of four research types. We see a decreased proportion of research question of the descriptive research type and an increased proportion of research questions of the explanatory research type.

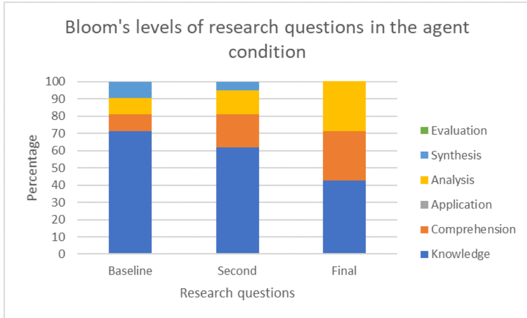
Figure 5.8b shows the classification of all research questions generated in the Agent condition as one of four research types. Here we see the same pattern as in the KCA condition: a decreased proportion of research questions of the descriptive research type and an increased proportion of research questions of the explanatory research type.

In both conditions, the distribution of types of research questions is increased from concentrated at the descriptive research type towards different types of research questions. In the Agent condition, the distribution is larger, and more quickly achieved, than in the KCA condition.

Statistical analysis The data was first tested for normality. A Shapiro-Wilk test showed the data was not normally distributed for the agent condition and the KCA condition. Hence we followed our data analysis plan and used two non-parametric Friedman tests of differences for the within-subject analysis. In both conditions the tests showed no significant differences

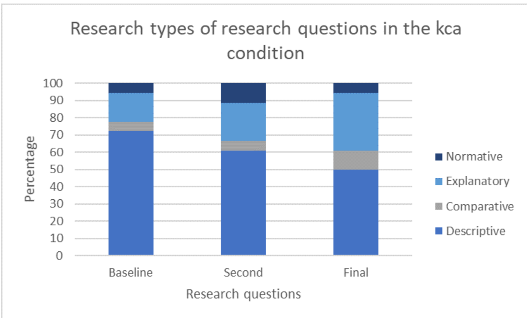


(a) All research questions generated in the KCA condition, classified with Bloom's taxonomy.

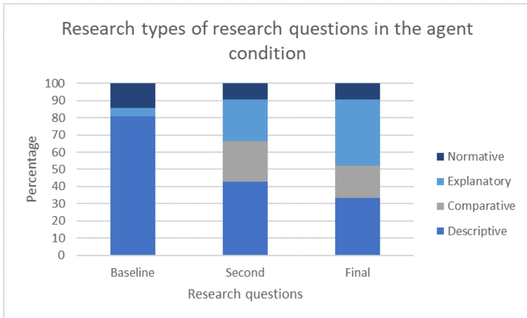


(b) All research questions generated in the Agent condition, classified with Bloom's taxonomy.

Figure 5.7: Classification of research questions with Bloom's taxonomy



(a) All research questions generated in the KCA condition, classified as different research types.



(b) All research questions generated in the Agent condition, classified as different research types.

Figure 5.8: Classification of research questions as research type

between the quality of the baseline, second and final research questions. For the Agent condition $\chi = 5.46$. For the KCA condition $\chi = 2.63$.

Tool comparison

To make a tool comparison, we compare the baseline research questions from the Agent condition with the baseline research questions from the KCA condition, the second research questions from the Agent condition with the second research questions from the KCA condition and the final research questions from the Agent condition with the final research questions from the KCA condition.

Classification with Bloom's taxonomy Figures 5.7a and 5.7b show that for the baseline research questions in both conditions, most research questions are at the "Knowledge" level. The other research questions are for the Agent condition pretty evenly divided over the "Comparison", "Analysis" and "Synthesis" levels, whereas in the KCA condition most other baseline research questions are at the "Comparison" level.

For the second research questions we see that in the KCA condition the majority of the research questions are at a higher cognitive level than the "Knowledge" level, while in the Agent condition, the majority is still at the "Knowledge" level.

For the final research questions on the other hand we see again more research questions at the "Knowledge" level for the KCA condition, while for the Agent condition the majority of the final research questions is at a higher cognitive level.

Classification as research type Figures 5.8a and 5.8b show that for the baseline research questions in both conditions most of the research questions are of the descriptive research type. Furthermore we note that for the Agent condition, most of the rest of the research questions are of the normative research type, while in the KCA condition most other research question are of the explanatory type.

For the second research questions we see that the research questions are quite evenly distributed over the four classes in the Agent condition. In the KCA condition we see that most research questions are of the descriptive type. Particularly the proportion of the comparative research types is smaller in the KCA condition, compared to the Agent condition.

For the final research questions the distribution of the research question over the four classes is quite similar. Noticeable is that the proportion of the descriptive research type is slightly larger in the KCA condition compared to the Agent condition.

Statistical analysis The data was again first tested for normality. A Shapiro-Wilk test showed the data was not normally distributed for the baseline research questions, the second research questions and the final research questions. Therefore we followed our data analysis plan and used three Wilcoxon rank-sum tests for the between-subject analysis. For the baseline research questions, the second research questions and the final research questions, the tests showed no significant differences in the quality of the research questions between conditions.

5.4.4 Questionnaire

A summary of the questionnaire results is shown in Table 5.2. All 40 participants filled out the questionnaire. The participants were mostly positive about the usability of both guidance tools, as the mean score is above the neutral score of 3. The participants were mostly neutral about the instructiveness and the usefullness of the guidance tools.

5.4.5 Use of check buttons

The check button number represented the amount of times the participant had pressed each "Check" button when filling in a research question.

Table 5.3 shows the mean amount of button clicks for each check button. In this table we see that there is no huge difference between the number of times the baseline check button, second check button in the KCA condition and the final check button were clicked, in other words the number of times the participants, presumably, changed their research question. The second check button in the Agent condition (so the button used to check the second research question in the Agent condition) is the exception. This check button was clicked on average more often than the other check buttons. Boxplots of the data show that for the second check button in the agent condition, there were three outliers. These participants clicked this button 9, 14 and 35 times respectively. These outliers are responsible for the difference in the means.

Two participants filled out their subject number instead of the check button number. The data of these participants was excluded from this analysis.

Table 5.2: Summary of Questionnaire results for both conditions.

Evaluation type	Question	Average Score Agent Condition	Average Score kca Condition
Usability	1. I understood how to use the guidance tool	3.8	4
	2. I found the guidance tool easy to use		
	3. I understood how to use the guidance tool quickly.		
Instructiveness	4. The guidance tool helped me to understand the process of formulating a research question	3.1	3.1
	5. The guidance tool helped me understand what a good research question is		
Usefulness	6. I found the guidance tool useful	3	3
	7. With the guidance tool I was able to write a better research question that I could have done without it		
	8. I would use such a guidance tool more often when formulating research questions		

Table 5.3: Mean number of check button clicks

Check button	Mean amount of clicks
Baseline check button	1.60
Second check button in KCA condition	1.19
Second check button in Agent condition	3.73
Final check button	1.71

5.5 Discussion

In this experiment we tested two digital tools, the Knowledge-Curiosity tool and the Agent tool. The research questions participants produced, were classified on Bloom's level and on research type and then transformed to numerical scores.

5.5.1 Knowledge and curiosity tests

From analysis of the results of the knowledge test, it appears that the fact questions were not too difficult for participants to answer, as we then would have expected the mean percentage of correctly answered question to lie lower. If the knowledge test were to be implemented in the actual Nature lab, the knowledge test should contain more test items and have for example multiple choice questions instead of true/false questions (Burton, 2010). This will give a more accurate representation of the knowledge level of the user than the knowledge test used in this digital prototype.

For the curiosity test all topics were chosen at least once, indicating the topics were a good reflection of the participants' existing interests. The topics "What bees and bumblebees eat" and “What bees and bumblebees contribute to the food supply” were chosen most often. The reason these topics were most popular might be that these topics were also discussed during the introductory lesson, especially the topic “What bees and bumblebees contribute to the food supply”, was central to the introductory lesson and might have primed the participants to choose this topic in the curiosity test.

5.5.2 Quality of the research questions

When comparing the baseline, second and final research questions, although not statistically significant, we observed a shift away from the “Knowledge” level and the descriptive research types towards research questions of a higher cognitive level or more complex research type. This suggests that both tools have a positive effect on the quality of the research questions, which is what we hoped to see.

When comparing the Knowledge-Curiosity tool and the Agent tool to each other, we found, as we expected, that the quality of the baseline research questions was similar in both conditions. In both conditions most baseline research questions were on the “Knowledge” level and of a descriptive research type. It seems the Knowledge-Curiosity tool has a stronger positive effect on the Bloom’s level of the research questions, whereas the Agent tool has a stronger positive effect on the research type of the research questions. The combination of the two tools does not seem to have any added benefits.

5.5.3 Questionnaire

A questionnaire was conducted to assess the opinion of the participants on three main evaluation points of the guidance tools (usability, instructiveness and usefulness). Participants were mostly positive about the usability of the tool and neutral about the instructiveness and the usefulness of the guidance tools. Interestingly, the participants in the KCA condition scored usability higher than the participants in the Agent condition. This indicates that the Agent tool is not as easy to use as the Knowledge-Curiosity tool. The fact that usability is scored positively, excludes it as an explanation for the neutral scores of instructiveness and usefulness. That instructiveness is scored neutrally could be due to the fact that participants did not recognise that they had learned something. The neutral score for instructiveness could explain the neutral score for usefulness. The guidance tools are meant to teach the user how to formulate a research question, if the tool fails, in the eyes of the user, at this objective, it seems logical the tool is not perceived as useful.

5.5.4 Use of check buttons

The check button numbers represent the average number of times participants checked their research questions. The results showed that the second check button in the Agent condition was on average clicked more often than the other three check buttons. Further analysis showed that this higher average was caused by three outliers. These outliers might represent participants that took the experiment seriously and worked hard to write a good second research question. We do not see the same outliers for the final research question, which might be explained by the fact that participants had to use the same guidance tool twice in the Agent condition and even these hard working participants did not feel the need to use the Agent tool extensively the second time.

These results imply that the Agent tool invites the user more to try different research questions, than the Knowledge-Curiosity tool does. However, the final check button (the check button used to check the final research question with the Agent tool) was not clicked with the same high frequency as the second check button in the Agent condition, which we would expect if the observed difference in clicks is due to the effect of the Agent tool. There might be an order effect at play here, as the participant might be bored or out of inspiration after having already written two research questions.

5.5.5 Limitations

A limitation to our study could be that all participants did the experiment at the same time. They were sitting behind a desktop computer or laptop next to each other. While each participant did have their own computer, some participants did look at each others screens and they talked to each other during the experiment. So it could be the case that some participants did not come up with their own research questions. There were two pairs of research questions that were exactly the same and multiple research questions that were similar in content. The participants working together could have influenced the overall results, this could have resulted in an overall lower quality of the research questions, as participants were distracted by each other when writing the research questions. But at the same time, studies have shown that discussion promotes more meaningful processing of the topic (Bielik & Yarden, 2016), so the participants working together can also have resulted in a higher overall quality of the research questions.

One other limitation in the set up of this experiment was that we could not log all activities of the students in the tools, instead all results were gathered through logging of data or forms filled out by the participants.

5.5.6 Conclusion

A digital prototype of the Agent tool and the Knowledge-Curiosity tool was implemented. An experiment was conducted in order to see what the effect of the digital prototypes was on the quality of the research questions. Exploratory analysis showed that there seems to be a slight shift away from research questions on lower cognitive levels and research questions of low complexity research types towards higher cognitive levels and more complex research types when the guidance tools are used. Exploratory analysis also suggests that there is a slight difference between the effect of the tools on the quality of the research questions. The Agent tool seems to have a stronger effect on the complexity of the research types of the research questions, while the Knowledge-Curiosity tool seems to help increase the cognitive level of the research questions more. There is no evidence that shows that one tool performs better than the other. Finally, it does not seem that the combination of the Knowledge-Curiosity tool and the Agent tool has an added benefit.

The research questions collected during the digital prototype testing are of a better quality than the research questions gathered during the preliminary research and of a comparative quality as the research questions collected during the paper prototype testing. This indicates that some form of guidance does have a positive effect on the quality of research questions students write.

The questionnaire shows that the usability of the tools was evaluated as good. Participants were however only neutral about the instructiveness and usefulness of the tools. The results do show an effect on the quality of the research questions, suggesting Bijennatuurlab can provide guidance to students learning how to formulate research questions.

Chapter 6

Discussion

6.1 Conclusion

In this thesis we tried to answer the question: *How can we utilize digital guidance to help children formulate good research questions?*. A preliminary research experiment was conducted to determine the quality of research questions students write without guidance. This provided insight into the manner and amount of guidance a guidance tool needs to provide. Based on design principles found in the literature, three paper prototypes were developed and tested. The results of the paper prototype testing lead to the development of two digital prototype guidance tools, the Knowledge-Curiosity tool and the Agent tool. We hypothesized that these digital guidance tools would have a positive effect on the quality of the research questions students write. The digital guidance tools were tested in an experiment and exploratory analysis of the results showed that both tools did seem to have a positive effect on the quality of the research questions.

In this chapter we will discuss whether the guidance tools provided the students with the right level of guidance, we will explore the role of metacognition in guidance tools and we will discuss the role of digital platforms in education. Finally, we will make some recommendations regarding important considerations when designing digital guidance tools and in particular when designing future versions of Nature lab.

6.2 Which level of guidance?

From the results of the digital prototype testing, we can conclude that both a tool that links a user's knowledge and interests with possible subjects and a digital agent that interacts with the user, can support the user in formulating research questions. But did the tools manage to get the best performance out of the high school students? In other words, did the tools provide the right level of guidance?

Through preliminary research and paper-prototype testing, we attempted to find the right level of guidance for children of 11 to 13 years old. The quality of research questions children of different ages are able to write might differ. Older children might on average be able to write research questions of a better quality than younger children. Aside from age differences, there are also individual differences, where one student might be more capable than another with regards to writing research questions. It should be considered that even with guidance it is difficult for children of this age to write research questions of a higher cognitive level or belonging to a more complex research type, simply because their cognitive development has not yet progressed to a point where they are capable of the abstract thinking necessary to write research questions of a better quality (See chapter 3 of Gelman (2014)). This would imply that the level of guidance we provided was correct, as we did observe a slight increase in quality.

Another possibility is that the guidance tools pushed the students in the direction of writing research questions of an average quality, instead of pushing to the highest possible levels. This has not been a conscious design decision, but this could explain the observed results. For example the subject "Number of bees found in different provinces of the Netherlands" leads to a research question such as "Which province has a bigger number of bees, Groningen or Limburg?", which is of a comparative research type and at an "Analysis" cognitive level. The subjects suggested by the Knowledge-Curiosity tool did not encourage the user to think about those subjects on a higher cognitive level, such as the "Synthesis" or "Evaluation" level. Moreover the characteristics of research questions provided by the Agent tool, mostly described research questions of a medium cognitive level and comparative or exploratory research type. Higher level research questions have similar characteristics as lower level research questions (after all research question types are theorized to be hierarchical), but the Agent tool did not provide any additional support to the user to help them write higher level research questions.

This could explain the relatively low proportion of research questions of a high cognitive level and high complexity. This does however not necessarily mean that the level of guidance provided by the tools was not right. We defined that one of the characteristics of a good research question is that it has to be answerable in the context of the Nature lab. Answering a research question of the "Synthesis" cognitive level or normative research type within the proposed format of the Nature lab would probably be hard or impossible, due to limitations on the type of data analysis tools available in the Nature lab. Therefore we conclude that the level of guidance provided by the digital tools was right within the context of this thesis.

6.3 Discrepancy between objective effect and user's affect

The digital prototype testing questionnaire showed that participants did not feel like the guidance tools helped them write better research questions, participants also indicated in the questionnaire that the guidance tools did not help them understand the process of formulating research questions better. These questionnaire results contradict the exploratory analysis of the results, that showed that the quality of the research questions written by the participants *did* improve. Here there appears to be room for metacognition to further improve the digital guidance tools.

Both the digital Knowledge-Curiosity tool and the digital Agent tool were developed with the intention of supporting one or more (meta)cognitive activities. The effect of the tools on cognitive activities can be derived from the usefulness score the participants gave and the effect of the tools on metacognitive activities can be derived from the instructiveness score. Both usefulness and instructiveness received neutral scores on the questionnaire post digital prototype testing. The exploratory analysis of the results showed that there is some effect on the quality of the research questions, if the students themselves did not notice their own improvement, this could be because the learning process was not explicit enough for them to gain the new metacognitive knowledge.

That usefulness was scored as neutral might be because the students did not feel like they learned anything from using the tool, as they might not have gained the new metacognitive knowledge. Another explanation might be that the tool did not support the cognitive activities as well as we had intended. This would mean the cognitive workload of the students was not sufficiently alleviated and the students would thus feel like the tool did not make things easier for them. On the other hand, these questions might also have been hard for students to answer, as it requires them to evaluate their performance with and without the guidance tool, for which they need metacognitive regulation. Metacognitive regulation is an acquired skill, which might not yet be fully developed in children (Alexander et al., 1995).

The questionnaire results suggest that in the current digital prototype the metacognitive aspects of the tools are not yet sufficient. Guiding the students through the inquiry process is not enough: students should also be made aware of their own progress, in order to properly acquire the inquiry skills that the guidance tools try to teach them.

6.4 Role of digital platforms in education

This thesis shows that digital guidance tools have the potential to be useful to students learning to write research questions. However, the advantages and disadvantages of the use of digital guidance tools as a replacement for "regular" lessons should be considered, before deciding on a course of action. An advantage of digital guidance tools is that they can be used at home and still provide the student with sufficient support. However, we also observed during the digital prototype testing, that students still turn to their teacher with their questions and look to them for approval. Moreover, students showed a natural tendency to discuss their work with their neighbours, these types of classroom dynamics are not as easy to incorporate in a digital tool.

Using a digital tool for inquiry-based learning has both advantages and disadvantages. Some of these advantages and disadvantages have already been discussed in section 2.1.3. During the digital prototype testing we observed one disadvantage ourselves, namely the digital tool did not facilitate the students' tendency to discuss their work with each other and with their teacher. In a classroom setting it is not a problem if no discussion tool is implemented, as students can talk to each other in real-time. For a web-application however this would be an important tool to include, as group discussion promotes self-reflection and more meaningful processing of the topic (Bielik & Yarden, 2016).

Until now we have mainly considered scenarios in which only a digital tool or only a non-digital teaching method is used. However as already stated in 2.1.3: a digital tool can never totally replace a human teacher. In fact research suggests that using one or the other might not be the optimal teaching method. Kapici et al. (2019) showed that students alternately using non-digital and digital laboratory environments performed better on conceptual knowledge tests than students who only used one of the two laboratory environments. But if a non-digital and digital teaching method need to work together to create the best learning result for the students, the role of the teacher needs to be considered during the design process of the digital tool.

Aside from facilitating class-room discussions on research topics, the teacher could also play an important role in the Orientation phase of the inquiry cycle. During the preliminary research and the paper prototype testing a relatively short introduction was given. During the digital prototype testing on the other hand, about half of the total experiment time was spent on introducing the topic. The participants in the digital prototype testing were very engaged with the introductory lesson and were enthusiastic about the topic, while during the preliminary research and the paper prototype testing we did not observe the same enthusiasm. Participants in the preliminary research and the paper prototype testing also had more trouble coming up with a research question. As Anderson et al. (1998) stated, motivated students are able to learn better, so the role of the teacher working in accordance with the Nature lab, could be to help introduce the research topic and to motivate the students.

6.5 Future work

During the digital prototype testing participants expressed a need for more concrete feedback on how good the research questions were that they wrote. Though we tried to include this type of feedback in the digital prototype, by marking important keywords in the research questions and showing what characteristics were present in the research question, the feedback might not have been explicit enough. As there are many different ways in which a good research question can be written, simply scoring the research question and providing that as feedback, might give the user the wrong impression about the quality of their research question. Instead it might be interesting to have the user reflect on the quality of their own research question after having conducted the whole research project. Having conducted the research project, it might be easier to recognise why it was a good research question or why it was not. Another idea is to have the user recognise good research questions before having to write their own.

Another shortcoming of this digital prototype was that the way the research questions were processed is very limited. Only words that were entered by hand could be recognised from the research questions. Using actual language recognition techniques will increase the adaptability of the tool and will make it easier to introduce different topics as the tool will not be limited to hard-coded words.

At the moment of this writing, the next version of the Nature lab is not yet finished, but the goal of Naturalis is to build a Nature lab that comprises all phases of the inquiry cycle. The guidance tools developed in this thesis only comprise the Questioning phase. If these guidance tools were to be integrated in the Nature lab, Naturalis should ensure that all phases connect to each other smoothly and are not treated as separate entities.

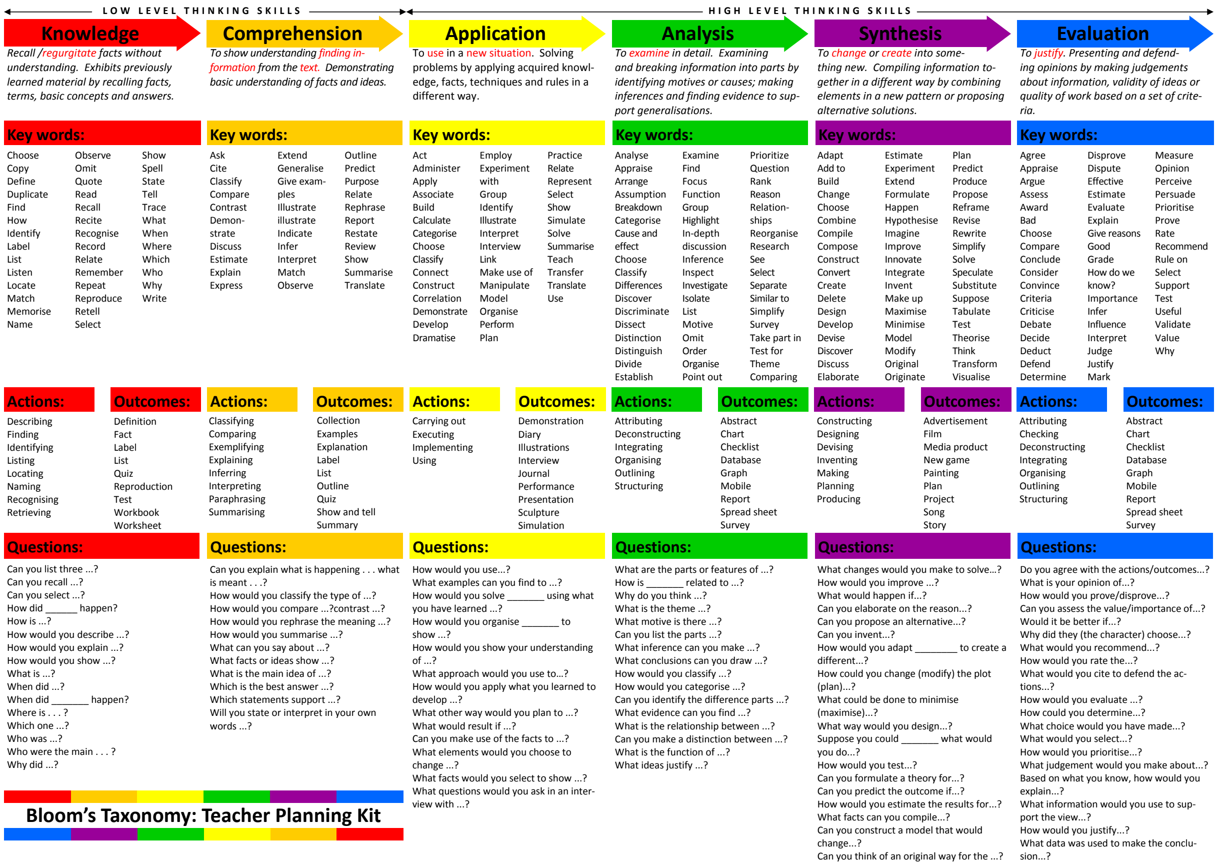
Finally it will be interesting to further develop a system that is adaptive to the user and able to support the user at a personal level. This can be done by for example further developing the Agent tool. In this digital prototype the Agent tool only looks at the research question the user writes and gives all users the same feedback if they write the same research question. If the Agent tool were to be applied throughout all the phases of the inquiry cycle, the agent could learn what the level of the inquiry skills of the user is and adapt the offered support to that profile. Such a guidance tool would also make it easier to use the Nature lab in different years of high school.

6.6 Concluding remarks

The results reported in this thesis showed that guidance does help students write research questions of a better quality. Our digital prototype, Bijennatuurlab, shows promise as a tool that supports the process of research question formulation. If Bijennatuurlab were to be integrated with the Nature lab, the connection of the Questioning phase to the other phases in the inquiry cycle should be taken into account. The Knowledge-Curiosity tool for example could be used to bridge the Orientation phase and the Questioning phase. As we observed no clear difference between the two guidance tools, either or both of the tools could be implemented to support the cognitive activities necessary in the Questioning phase. To ensure the user is aware of the material they learned in inquiry-based learning, metacognitive activities should be supported by the guidance tool. Finally, if possible, a combination of digital and non-digital teaching methods are preferred over using digital tools alone. However, this thesis showed that digital tools can successfully guide students in inquiry-based learning.

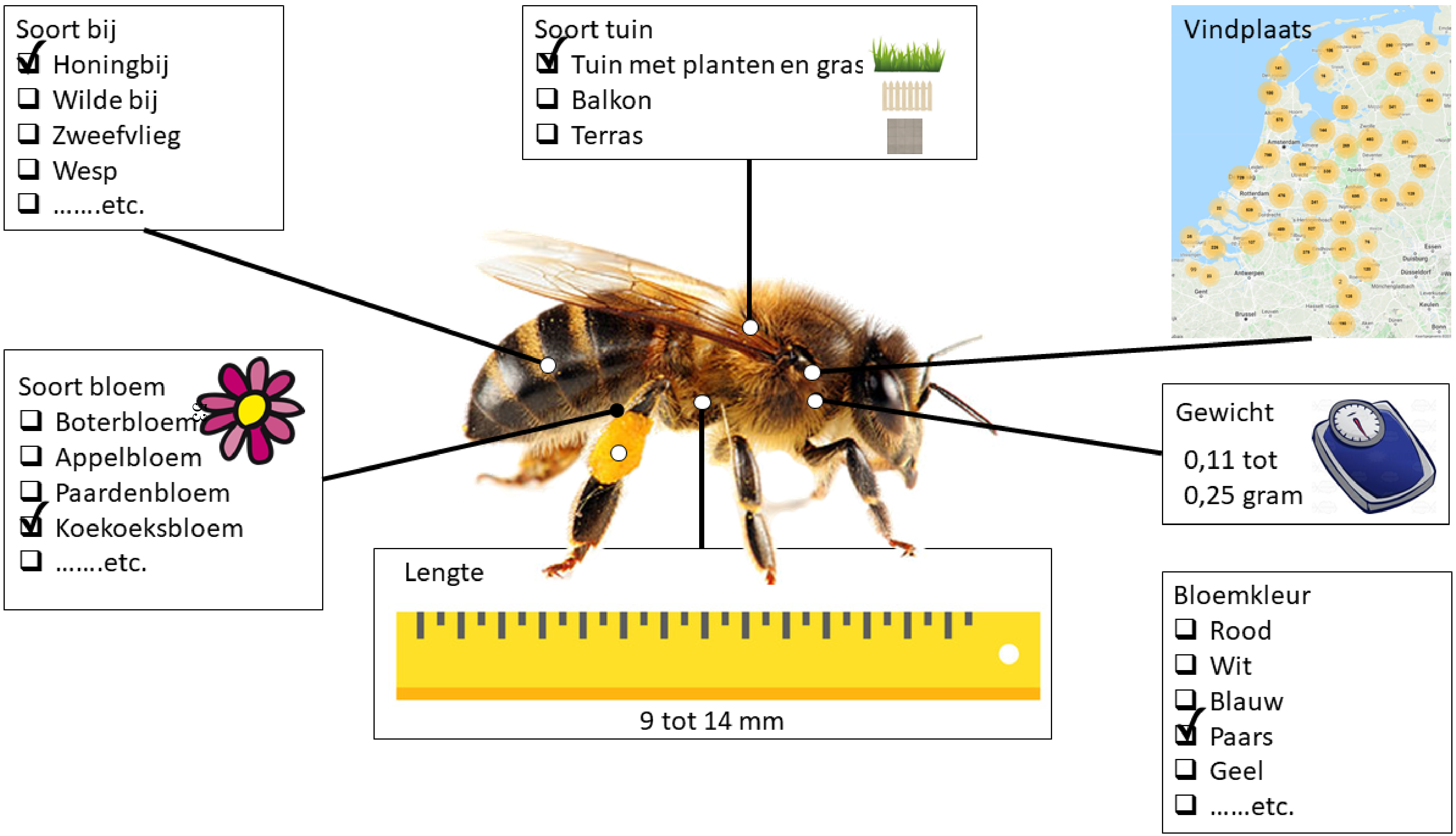
Appendix A

Bloom's taxonomy



Appendix B

Infographic


Soort bij
☑ Honingbij
☐ Wilde bij
☐ Zweefvlieg
☐ Wesp
☐ …….etc.
Soort tuin
☑ Tuin met planten en gras
☐ Balkon
☐ Terras
Vindplaats
Soort bloem
☐ Boterbloem
☐ Appelbloem
☐ Paardenbloem
☑ Koekoeksbloem
☐ …….etc.
Lengte
9 tot 14 mm
Gewicht
0,11 tot
0,25 gram
Bloemkleur
☐ Rood
☐ Wit
☐ Blauw
☑ Paars
☐ Geel
☐ ……etc.

Appendix C

Knowledge tool forms

1. Op het platteland komen de meeste bijen voor. **Juist/Onjuist**
2. De weidehommel is de meest algemene soort in Groningen Stad. **Juist/Onjuist**
3. Er zijn meer bijen in Groningen Stad dan in Leiden. **Juist/Onjuist**
4. Voor de tweekleurige koekoekshommel moet je in Groningen zijn. **Juist/Onjuist**
5. Op het waddeneiland Texel komen meer dan 100 hommels voor. **Juist/Onjuist**
6. Hommels zijn wilde bijen. **Juist/Onjuist**
7. In Nederland leven meer dan 350 soorten wilde bijen. **Juist/Onjuist**
8. Alle bijensoorten zijn heel sociaal en leven met z'n allen in een nest. **Juist/Onjuist**
9. Alle bijen verzamelen nectar om honing van te maken. **Juist/Onjuist**
10. De aardhommel maakt zijn nest onder de grond in verlaten muizenholletjes. **Juist/Onjuist**

- In welke omgeving komen de meeste bijen voor? *- Waar komen meer bijen voor, in de stad of op het platteland?*
- Welke hommelsoort komt het meest voor in Groningen Stad? *-Komt de tweekleurige koekoekshommel voor in Groningen?*
-Waar zijn meer honingbijen geteld, in Groningen Stad of in Leiden? *-Zijn er in Rotterdam meer weidehommels of meer tuinhommels?*
-Welke hommelsoort komt het meest voor in Groningen Stad? *-Komt de tweekleurige koekoekshommel voor in Groningen?*
-Hoeveel hommels zijn er geteld in Assen? *-Zijn er in Rotterdam meer weidehommels of meer tuinhommels geteld?*
- Hoeveel soorten bijen zijn er bekend in Nederland? *- Welke kenmerken heeft een wilde bij?*
- Hoeveel soorten bijen zijn er bekend in Nederland? *- Welke kenmerken heeft een wilde bij?*
-In wat voor nest leven aardhommels? *-Hoeveel bijen leven er gemiddeld in een kolonie?*
-Waarom verzamelen bijen nectar? *-Waarom dansen bijen?*
-In wat voor nest leven aardhommels? *-Hoeveel bijen leven er gemiddeld in een kolonie?*

Instructies prototype 3

1. Beantwoord de feitvragen op de kaarten door juist of onjuist te omcirkelen.
2. Controleer of je de feitvragen goed beantwoord hebt met het antwoordblad. Leg de kaarten die je fout beantwoord hebt links van je, leg de kaarten die je goed beantwoord hebt rechts.
3. Pak de fout beantwoorde kaarten links van je en draai ze om.
4. Achterop de kaarten worden een aantal onderzoeksvragen voorgesteld. Kies een of meer onderzoeksvragen die je interessant lijken. Schrijf die hieronder op.

5. Gebruik de gekozen onderzoeksvragen om zelf een eigen onderzoeksvraag op te schrijven.

Uiteindelijke onderzoeksvraag:

Antwoord feit vragen

1. Op het platteland komen de meeste bijen voor. **Juist**
2. De weidehommel is de meest algemene soort in Groningen Stad. **Onjuist**
3. Er zijn meer bijen in Groningen Stad dan in Leiden. **Onjuist**
4. Voor de tweekleurige koekoekshommel moet je in Groningen zijn. **Juist**
5. Op het waddeneiland Texel komen meer dan 100 hommels voor. **Onjuist**
6. Hommels zijn wilde bijen. **Juist**
7. In Nederland leven meer dan 350 soorten wilde bijen. **Juist**
8. Alle bijensoorten zijn heel sociaal en leven met z'n allen in een nest. **Onjuist**
9. Alle bijen verzamelen nectar om honing van te maken. **Onjuist**
10. De aardhommel maakt zijn nest onder de grond in verlaten muizenholletjes. **Juist**

Appendix D

Word-block tool form

Question words

- Wat
- Hoe
- Waarom
- Welke
- Waar
- Hoeveel
- Wanneer

Conditional words

- meest
- minst
- minder
- meer
- grootste
- kleinste
- langste
- kortste

Filler words

- in
- de
- is
- het
- een
- zijn
- kunnen
- op
- er
- kan
- met
- niet
- van
- dat
- hij
- zij
- uit
- we
- geen
- heeft
- hebben
- en
- of

Appendix E

Agent tool forms

Checklist goede onderzoeksvraag

Instructies:
Bekijk de onderzoeksvraag van je klasgenoot. Als de vraag voldoet aan een eis, vul dan het puntenaantal in de score-kolom in. Als je denkt dat de vraag niet helemaal voldoet aan de eis, kan je ook maar een deel van de punten geven. Als je alle eisen gecontroleerd hebt, tel dan de totale score op en vul die onderaan de kolom in.

Eis	Voorbeeld	Punten	Score
Gaat de vraag over het onderwerp bijen?		1	
Is de zin een vraag?	Kijk of de zin eindigt met een vraagteken of begint de zin bijvoorbeeld met een werkwoord (kunnen/hebben/doen)	2	
Zit er een vraagwoord in de zin?	Hoe, wat, welke, waarom, waar, hoeveel, wanneer	2	
Zitten er een of meerdere variabelen in de zin?	Omgeving, Plek, Bijensoort, Gewicht, Lengte, Bloemsoort	3	
Wordt er gevraagd naar een vergelijking tussen twee variabelen?	Kijk of er woorden in de zin zitten als: groter, kleiner, meer, minder, langer, korter, zwaarder, lichter	4	
Denk je dat de vraag is te beantwoorden met een onderzoeksactiviteit?	Kijk of de vraag te beantwoorden is met een activiteit die je kunt doen, bijvoorbeeld tellen, meten, vergelijken, wegen	5	
		Totaal aantal punten: 17	**Totale score:**

Voor de vraagsteller

1. Bedenk een onderzoeksvraag dat te maken heeft met het onderwerp “bijen”. Schrijf deze onderzoeksvraag hier beneden op.

2. Wat zou het antwoord kunnen zijn op je onderzoeksvraag?

3. Hoe zeker ben je van je antwoord op je onderzoeksvraag? (1=heel onzeker, 2=onzeker, 3=niet zeker en niet onzeker, 4=zeker, 5=heel zeker).

Doe de onderstaande opdracht pas nadat je vraag is nagekeken!

4. Je hebt commentaar gekregen van een klasgenoot aan de hand van een score op een aantal eisen. Gebruik dit commentaar om je onderzoeksvraag te herschrijven.

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