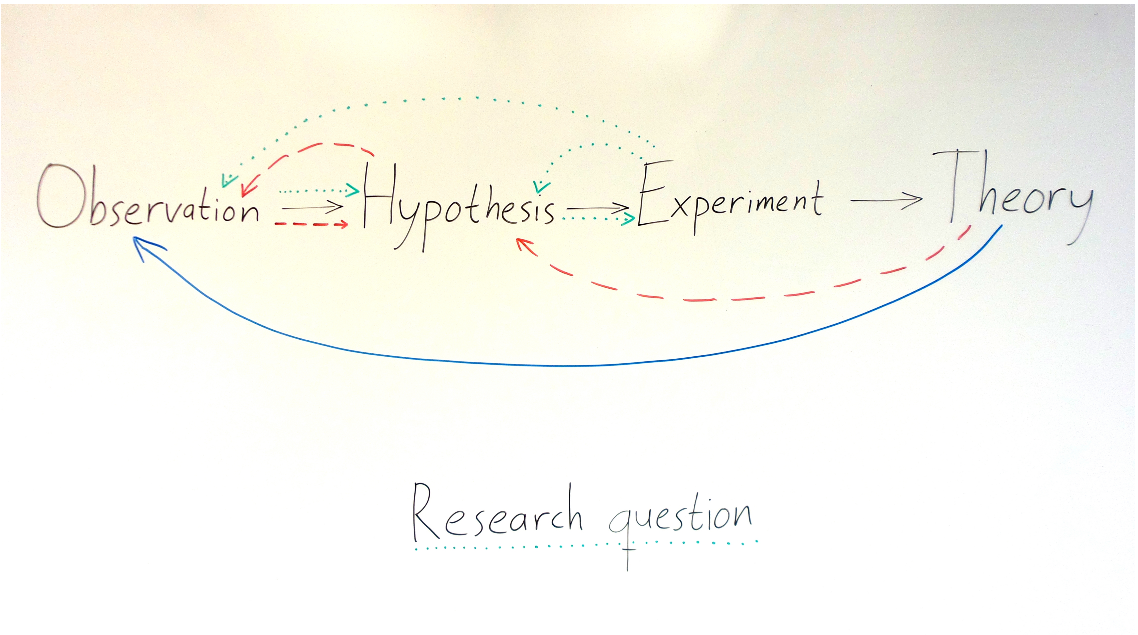

Teaching and Learning About Hypotheses

-Designing and evaluating a sequence of physics labs in upper secondary school

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Abstract

The objective for this thesis is to contribute to the understanding of how to teach explicitly about hypotheses in upper secondary school physics. This is a part of the discussion on how to teach explicitly *about* scientific inquiry, and deals with the problem of how to come to terms with common misconceptions about hypotheses. A sequence of laboratory sessions is developed and implemented in a first-year upper secondary school class. The sequence aims to give the students opportunities to develop their conceptions of the hypothesis concept. This is achieved by drawing on the notion of constructive alignment and through a combination of interrelated teaching and learning activities: direct instruction, activities of scientific inquiry and reflection assignments. Using data from students' definitions of the hypothesis concept, work sheets, laboratory reports and interviews, the sequence is evaluated through analysis of the students' conceptual development, changes in their general approaches to scientific inquiry, and causes for their learning. Five important aspects of the hypothesis concept are identified, and conceptual development concerning each of these are assessed. The degree of conceptual development is found to be dependent on the students' abilities to discern an aspect in different types of teaching and learning activities. Changes towards more reflective approaches to scientific inquiry are noted among many students. These changes are strongly connected to a guided reflection assignment that relate to students' practical performance and that are built on extensive feedback. The results of this study suggest that the developed sequence can provide examples of design for effective teaching about hypotheses and scientific inquiry.

KEYWORDS: physics, hypothesis, scientific inquiry, reflection, laboratory, constructive alignment

Sammanfattning

Målsättningen för detta examensarbete är att bidra till förståelsen av hur explicit undervisning om hypoteser i gymnasiets fysikkurser kan utformas. Detta är ett bidrag till diskussionen kring hur undervisning *om* vetenskapligt undersökande kan se ut, samt hur vi kommer tillrätta med vanligt förekommande missuppfattningar om hypotesbegreppet. Som ett led i detta utvecklas en lektionssekvens som sedan genomförs i en fysikklass som läser första året på gymnasiet. Sekvensen syftar till att ge eleverna möjlighet att utveckla sin begreppsförståelse om hypoteser. Utifrån ideer inom constructive alignment uppnås syftet genom att tre olika typer av lärandeaktiviteter, direkt instruktion, vetenskapligt undersökande samt reflektion, samverkar för att lyfta fram samma innehåll. Data samlas in via studenternas definitioner av hypotesbegreppet, arbetsblad, laborationsrapporter och intervjuer. Lektionssekvensen utvärderas sedan genom analys av utvecklingen i studenternas begreppsförståelse, deras förändrade angreppssätt till vetenskapligt undersökande, samt orsaker till de lärdomar som framkommer. Fem viktiga aspekter av hypotesbegreppet identifieras, och förändringen av elevernas begreppsförståelse analyseras för varje aspekt för sig. Hur mycket begreppsförståelsen förbättras visar sig bero på hur synliggjord en aspekt är i de olika typerna av lärandeaktiviteter. I allmänhet framträder ett mer reflekterande angreppssätt till vetenskapligt undersökande hos många elever. Den här förändringen kopplar starkt till en specifik reflektionsuppgift som bygger på elevernas tidigare praktiska utförande och som innehåller stor grad av återkoppling från läraren. Dessa resultat pekar på att den utvecklade lärsekvensen kan ge flera exempel på hur verksam undervisning om hypoteser och vetenskapligt undersökande kan utformas.

NYCKELORD: fysik, hypotes, vetenskapligt undersökande, reflektion, laboration, constructive alignment

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First of all, many thanks to my supervisor Tom Adawi, for helping me through the maze of pedagogical concepts, possible structures, and explanatory models. Being an intense listener, he could often suggest to me what it was I tried to explain, or point to someone who had explained it before.

Great thanks also to Lars Hanning, the upper secondary school teacher who invited me to his class and allowed me to use almost five of his lectures for this study. Not only did he help arrange things practically, but we've also had lots of interesting discussions about possible improvements for the sequence, observations of the classroom, and how the teachers' own conceptions of scientific inquiry matter.

The students are due many thanks as well, for enthusiastically engaging in my sometimes rather demanding sessions. Especially those who participated in the interviews, who despite some initial nervousness have provided me with most interesting data and coped with my seemingly never ending questions of "why?", "how do you know that?" and "can you give an example?".

Writing in English has been a challenge to me, especially translation, and it would not have been as good without the help of my loved friend Saga Bokne, who has made hundreds of small corrections and suggestions for formulations. Also, thanks to my classmate Robin Wilsson, who despite lack of time is the only one who made serious commenting of my abstract.

Thanks also to my examiner, Samuel Bengmark, who helped me through the initial phase of getting this idea accepted as a valid thesis subject. But mostly for his mentoring through my years at the master programme Learning and Leadership.

Contents

1 INTRODUCTION

1.1 Motivation

The Swedish National Agency for Education (Skolverket) has created a subject plan for physics as well as syllabuses for the different physics courses in the Swedish upper secondary school. In both the described purpose of the subject and the specified syllabuses, scientific inquiry takes a central role. Hypotheses are a natural part of this and are mentioned in the purpose and as central content of all the physics courses. Quotes in selection from The Swedish National Agency for education, on Physics and regarding hypotheses, are presented here (Skolverket 2014):

Purpose Physics is constantly being developed in interaction between theory and experiment, where hypotheses, theories and models are tested, re-assessed and modified. Teaching should thus cover the development, limitations and areas of applicability of theories and models.

Teaching in the subject of physics should give students the opportunities to develop the following:

Knowledge of the concepts, models, theories and working methods of physics, and also understanding their development.

The ability to analyse and find answers to subject-related questions, and to identify, formulate and solve problems. The ability to reflect on and assess chosen strategies, methods and results.

The ability to plan, carry out, interpret and report experiments and observations, and also the ability to handle materials and equipment.

Core content, Physics 1,2 and partly 3:

The nature, working methods, and mathematical methods of physics.

-The importance of experimental work in testing, re-assessing and revising hypotheses, theories and models.

-Planning and implementation of experimental investigations and observations, and formulating and testing hypotheses in connection with this.

-Assessing results and conclusions by analysing choice of methods, work processes and sources of error.

Historical overviews show that laboratory work has been a central point in research, curriculum and other steering documents for more than half a century in various parts of the world. Still, hard evidence for the importance of laboratory work seems hard to find, and every focus have its own drawbacks. In particular, there seems to be a tendency for school systems to give students two false and counterproductive impressions of the nature of science. Firstly, that there is a generic scientific method that can be applied to all science contexts. Secondly, that this method can be applied linearly in discrete steps as a checklist that, if followed correctly, will be certain to produce results (Trumper 2003).

Gyllenpalm (2010) investigates the customs of science teaching in both teacher education programmes and secondary schools. Focusing on inquiry in science education, he is especially interested in the learning *about* scientific inquiry, which relates to the selected quotes above. Gyllenpalm concludes that there are differences in uses of many scientific concepts between the school context and the context of actual scientific investigation. He also shows that there seems to be little effort made to teach scientific inquiry methods explicitly in the Swedish secondary school. Furthermore, this practice seems to lead to specific misconceptions about scientific inquiry, as well as strengthen the general problematic views presented by Trumper above.

It is proposed by previous research that steps should be taken to teach more specifically *about* scientific inquiry, as being part of the *nature of science* (Bartholomew *et al.* 2004, Schwartz *et al.* 2004). When doing this, it is important to take into consideration that teaching about scientific processes without linking them to scientific content can also strengthen the view of a generic and linear scientific method (Hodson 1996). Thus emerges a need for explicit teaching about scientific inquiry, closely linked to the practice of experiments and based on scientific content.

The hypothesis is one of the central concepts in *the nature of science* (Bartholomew *et al.* 2004). Gyllenpalm investigates the hypothesis concept specifically, and notes serious differences between school and science contexts. One of the main problems identified is the use of hypotheses as mainly a pedagogical tool, a prediction at the beginning of a session or shorter experiment. This, Gyllenpalm argues, could stem from the constructivist idea that a false prediction might cause a cognitive conflict for the student, giving opportunities for learning. In this way, the use of the hypothesis concept in school differs from the scientific use. Gyllenpalm calls for a discussion on the use of the word hypothesis in school, and means of coming to terms with the misinterpretations of hypotheses as random guesses, used in generic and linear scientific inquiry processes (Gyllenpalm 2010). This thesis is a contribution to that discussion, proposing and evaluating practical examples of teaching and activities designed to improve students' conceptions of hypotheses.

1.2 Purpose and research questions

The purpose of this thesis is to contribute to the understanding of how to teach to help students' develop their conceptions of the nature and role of hypotheses in scientific inquiry.

A sequence of sessions is created that can serve as an example of how to teach explicitly about hypotheses and their use in scientific inquiry. Development in students' conceptions of hypotheses are evaluated, as well as general changes in approach to scientific inquiry. Causes for learning and implications for further teaching efforts in this area are then discussed, and complemented with concrete recommendations for teaching.

Four research questions are specified to evaluate this sequence and help fulfil the purpose.

Research questions (RQ) :

1 What development in students' conceptions of hypotheses can be seen after the sequence?

2 Are there any major effects on students' general approaches to scientific inquiry?

3 What can be said about causes for conceptual development and changes in the student's general approaches to scientific inquiry?

4 How can meaningful explicit teaching about the hypothesis concept and its use in scientific inquiry be designed?

RQ 4 is the major objective for the study. RQ 1-3 are mainly tools to better answer RQ 4 with evaluation of the sequence and new implications for teaching. Conceptual development is considered at a collective level.

1.3 Demarcation

First of all, the students' entire view of the nature and methods of scientific inquiry is not included in the interventions, or investigated in the evaluations. Only questions that relate directly to the concept of hypotheses are considered. These include the link between hypotheses and observations as well as hypotheses and experiments, but not for example representation of data or how hypotheses and experiments are used to form theories. Moreover, the effect of the intervention on students' learning of scientific content is not investigated.

While the sequence of interventions has the purpose to enhance long term learning among the students, the evaluation of the interventions only concerns learning in the short term. Furthermore, no comparison to other classes is done.

During the laboratory sessions, students work mainly in groups of two, with some use of larger groups for discussions. This choice is made with the assumption that the intended learning is more efficiently reached this way, but no investigation is made of the impacts of group work and communication.

1.4 Thesis layout

In the Background chapter, a view on scientific inquiry is presented, which provides the basis for communication with the students about scientific inquiry during the sequence. Furthermore, pedagogical inspiration for the design of the sequence is included.

In the Method chapter, the designed sequence is introduced in a detailed overview. Furthermore, the methods of data collection and data analysis are presented.

In the Results chapter, a classification of students' conceptions of hypotheses is introduced. Results are presented on development in students' conceptions of hypotheses and general approach to scientific method. Also, a closer look on results and quotes from a particularly influential guided reflection activity is included.

In the Discussion chapter, the sequence is evaluated. Firstly, evaluation of the different types of teaching and learning activities are presented. Secondly, the conceptual development and correlation in design are elaborated upon. These two parts are then summarised to form conclusions on causes for learning.

In the Conclusions chapter, the research questions are answered with a summary of all previous chapters. Implications for teaching are presented through concrete recommendations for further teaching. There are also short suggestions for future research.

2 BACKGROUND

This chapter consists of two parts. Firstly, a view of scientific inquiry is introduced, which provides the basis for communication with the students about scientific inquiry during the sequence. It is a non-comprehensive summary, and selection is based on what is judged meaningful for students at the upper secondary school level. Secondly, pedagogical inspiration for the design of the sequence is presented.

2.1 A view of scientific inquiry

The view of scientific inquiry used in this thesis and in the sessions is mainly based on Alan F Chalmers "What is this thing called science?" (Chalmers 1999). The main characteristics selected are the following:

- There is no one scientific method that can bee applied in all contexts. Scientific methods depend on the nature of the subject studied as well as the amount of previous theory available, and different methods can be equally useful for the same problem.
- Observations and experiments are theory dependent. This means that your theoretical understanding can influence both what you observe, but also what experiments you can propose, and how these experiments are interpreted.
- Observations are qualitatively different from experiments. While an observation can be done in any context about any phenomena, an experiment is a deliberate and controlled manipulation of circumstances to investigate some relation or explanation.
- Science is a not a linear process. Rather, it is iterative, and no exact process can be specified. Science is non-linear both when considering long-term perspectives like the shaping of theories, and on the level of producing specific experimental results.

Furthermore, since the concept of hypothesis is the focus area of this thesis, the main aspects of the hypothesis concept are summarised here:

- A hypothesis is tentative.
- A hypothesis is testable by experiment.
- A hypothesis includes some explanation or causal relation.
- A hypothesis is an important tool in scientific inquiry, guiding further experiments and helping to build knowledge from results.

- A hypothesis is built on observations and previous experiments, but also accepted theory.

2.2 Pedagogical considerations

The aim of the sequence presented in this thesis is to deepen the students' understanding of the nature of hypotheses and their role in scientific inquiry. This is in line with calls for more explicit teaching about scientific inquiry. Previous research shows that this cannot be aquired simply by letting students experience and participate in scientific inquiry activities (Schwartz *et al.* 2004).

Furthermore, the notion that scientific inquiry can be learnt in a content free way, has been criticised (Hodson 1996). Hodson argues that if we never focus on the content while discussing the nature of scientific inquiry, we will put forward the view that there are generic, linear processes which, if used correctly, are appropriate to all scientific contexts. This view of science is not compatible with the first characteristic of scientific inquiry specified in the previous section, and talk of generalisable skills regardless of context should be avoided.

In conclusion, a combination of proper experience, guided attention and explicit reflection is called for (Abd-El-Khalick and Lederman 2000). These different parts of teaching should strengthen one another, and lend credibility and perceived usefulness to the new views. Thus, the focus on ideas about scientific inquiry is complemented with a focus on scientific inquiry processes.

The focus on teaching and learning about scientific inquiry is communicated to the students through learning objectives, and both assessment and feedback emphasise the more general aspects of hypothesis use. In short, the whole sequence is structured for working towards a specific goal. This idea is in line with the notion of *constructive alignment* (Biggs 1996). The following description of constructive alignment by Biggs captures much of the pedagogical inspiration for the design of the sequence (Biggs 2003, p. 27):

> "The curriculum is stated in the form of clear objectives, which state the level of understanding required rather than simply a list of topics to be covered. Teaching methods are chosen that are likely to realize those objectives; you get students to do the things that the objectives nominate. Finally, the assessment tasks address the objectives, so that you can test to see if the students have learned what the objectives state they should be learning. All components in the system address the same agenda and support each other"

In "The Power of Feedback", Hattie and Timperley focuses specifically on the role of different types of feedback and their respective efficiency in reducing the gap between the present state of the student's understanding and the sought goal. Feedback on the process is an often neglected but potentially powerful tool (Hattie and

Timperley 2007). This kind of feedback is therefore an important part of the developed sequence.

One strategy used in the sequence to avoid exhibiting an incorrect view of scientific inquiry is to mention potential misconceptions. This strategy will, however, have only a minor effect if the rest of the session or sequence supports the incorrect view. Therefore, the sessions are designed to challenge misconceptions about the use of hypotheses in scientific inquiry. Furthermore, new ideas about hypotheses are taught through discussion and reflection, with and among students. This is intended to support the view that methods are judged not by striving to do science in *the* correct way, but through discussing and analysing their usefullness. The idea that the students need experiences that fit with a new view, and through these experiences and discussions about them arrive at new conceptions, is in line with a constructivist perspective on learning (Säljö 2010).

Most of the sources cited above argues for inclusion of extensive time for guided reflection about the usefulness of hypotheses in the sequence. Abrahams and Millar investigate the importance of planning explicitly for students to reflect on central ideas during laboratory sessions. Otherwise, there is a tendency for students to focus only on the practical tasks at hand, and ideas from other sessions are not related to the activity (Abrahams and Millar 2008). Hence, some of the design is intended to focus the students on the use of hypotheses in scientific inquiry, also during otherwise practical laboratory sessions.

To summarise, the aim of the developed sequence is to help students focus on the hypothesis concept and its use in scientific inquiry. This sequence includes direct instruction about the concept of hypothesis. It also includes activities where students investigate actual science (here: physics) content. These activities should challenge common misconceptions and should not be in conflict with the view of scientific inquiry described above. Furthermore, active and guided reflection should be the key to help students focus on the concept of hypothesis and its implementation. The students are meant to evaluate their own and others' efforts in order to develop conceptions that are meaningful to them, and hopefully closer to the view of hypotheses in scientific inquiry described above.

These different teaching and learning activities should be closely interrelated, so that they strengthen one another. Feedback from the teacher is of critical importance to establish these links and keep the focus on the process. Throughout the sequence, the students should gain an understanding of what they are doing and why they are doing it. An overview of the three main teaching and learning activities and their relations to one another, is presented in Figure 2.1.

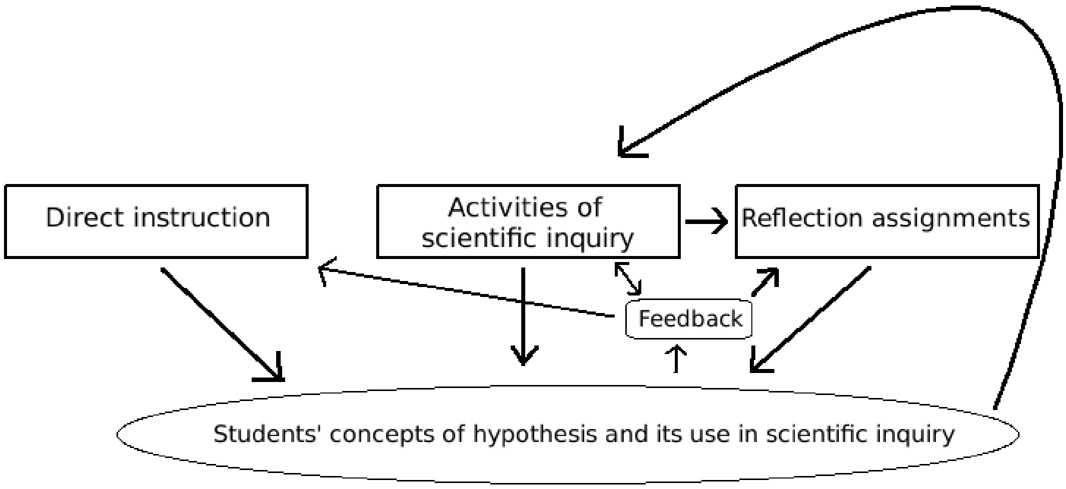

Figure 2.1. The three main types of teaching and learning activities and their relations. Through *direct instruction* ideas of the nature and role of hypotheses are presented. The *activities of scientific inquiry* are designed, as described above, both to present a view of scientific inquiry, and to serve as a basis for reflection. The *reflection assignments* help the students focus on aspects of hypotheses in scientific inquiry that do not necessarily follow from the activities. The teacher observes during the sessions and gathers data from written reflections, work sheets and laboratory reports to use as feedback for the students in all activities, but most importantly in reflection. All types of activities can potentially influence students' conceptions, which in turn affects their activities of scientific inquiry.

3 METHOD

This chapter includes three sections. Firstly, the design of the sequence is presented. Secondly, the data collection is described. Thirdly, the methods for analysing the data are introduced.

The first part of the work presented in this thesis consists of the development and delivery of a sequence of sessions with the aim to aid the students in improving their understanding of the nature and role of hypotheses in scientific inquiry. The second part includes gathering and analysing data from these sessions and interviews, in order to be able to answer the research questions. In this sense, the design of the sequence is also a result, but is presented here as the first part of the method, since it is the basis for my data collection.

3.1 Design of the sequence

This section includes the first part of the answer to RQ 4, by giving an example of a sequence designed for explicit teaching about hypotheses. The sequence consists of five sessions, three of which are mainly laboratory sessions. The aim and intended learning outcomes are specified as follows:

Aim The student develops a better understanding of the concept of hypothesis, and why it is useful in scientific inquiry.

Intended learning outcomes

(a) The student is able to present a definition of the concept of hypothesis including some of the major aspects.

(b) The student can identify differences and similarities in proposed definitions of the hypothesis concept.

(c) The student expresses some of the major aspects of the hypothesis concept when discussing their own conceptions about hypotheses.

(d) The student can describe, through examples or abstract reasoning, how hypotheses are used in scientific inquiry, and how inclusion or exclusion of different aspects of the concept influences the scientific inquiry process.

(e) The student can formulate hypotheses using observations and previous knowledge.

(f) The student can independently plan and perform experiments that test hypotheses.

(g) The student can draw conclusions on and refine hypotheses based on experimental results.

The focus of the sequence is to challenge common misconceptions about hypotheses and help the students develop a more informed view of hypotheses and how they are used. In this thesis, it is mainly the effects of the sequence on intended learning outcomes (a-d) which are evaluated.

The specified aim and intended learning outcomes also serve the larger purpose of helping the students develop a better understanding of scientific inquiry in general. This should provide students with tools for active reflection on the methods they are using, and how they can be improved.

3.1.1 A model of scientific inquiry

A model of scientific inquiry is developed, intended for use during the interventions, as one of the means in working towards a better understanding of the use of hypotheses in scientific inquiry. It is used as a framework in communicating the main aspects of the hypothesis concept and its use, as well as describing the larger context of scientific inquiry. A visual representation of the model, as shown to students, can be seen in Figure 3.1.

For specific examples of how the model is used during teaching, see appendix A. The main idea is to draw the arrows during discussions in class, to show what we have done during the different sessions. For details on sessions, see section 3.1.2 below.

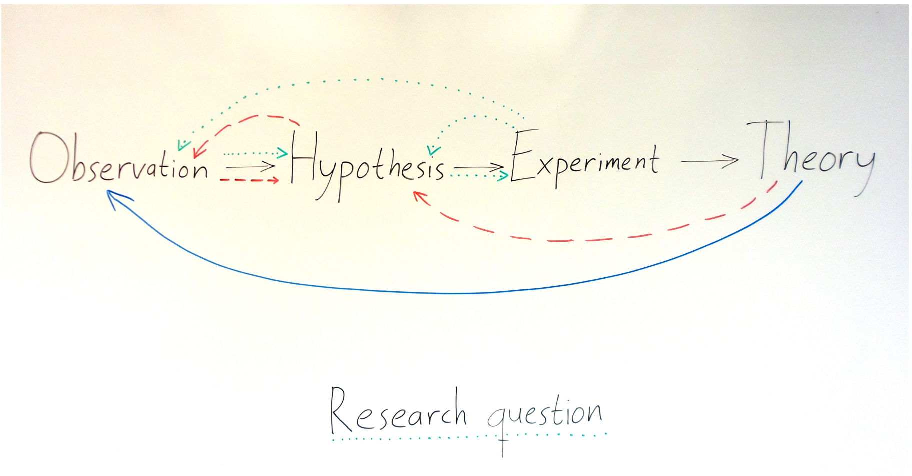

Figure 3.1. The model of scientific inquiry as shown to the students. Filled arrows represent what is discussed in session 1. The dashed arrows (red), are included in session 2, and the dotted arrows (green) are used during session 4 for feedback and explanation of session 3. “Research question” is introduced at the end of session 4 as preparation for session 5.

Several alterations and simplifications are used in the model compared to the philosophy of science presented by Chalmers (1999). For example, the method of predicting results using hypotheses is left out of the description for the students. Falsification is only mentioned as a method, by the claim that a hypothesis can never be thoroughly proven, and to search for ways to disclaim the hypothesis can be an efficient research method. It is not included in the theoretical discussion about the nature of hypotheses.

3.1.2 An overview of the sessions

A full description of the five sessions can be found in appendix A. Below, a short overview of the sessions and their intended learning outcomes are presented. Of the intended learning outcomes specified in the previous section, (a-d) are supposed to be reached through a combination of all sessions, while (e-g) are included and specified for the different sessions. Also, some specific activities for (b) are included.

Session 1: Introduction - 40 min

During the first session, the concept of hypothesis and its role in scientific inquiry is introduced, and the purpose of the sequence explained.

In this session, the students first answer the question “what is a hypothesis?”. Then the nature of scientific inquiry and the role of hypotheses are briefly discussed. The model linking observation, hypotheses, experiment and theory to each other in the context of scientific inquiry is introduced, without including the research question. A demonstration is carried out, showing an example of hypotheses use in scientific inquiry. Simultaneously, a discussion is held about benefits of using hypotheses to propose experiments, relating to the model.

Session 2: Formulating hypotheses and discussing their use - 80 min

The second session is a laboratory session where the students investigate different representations of the concept of torque. Torque is not a part of their curriculum.

Intended learning outcomes for the session:

- The students can draw conclusions from their observations and previous knowledge to formulate hypotheses. (e)
- The students are familiar with comparing hypotheses. (b)

Students work in pairs on four different laboratory stations. They spend about five minutes at each station, carrying out tests and observing consequences in order to be able to formulate a hypothesis. On one occasion for each group, they stay at a station after having finished the task, observing how the next group tackles the problem, and comparing with their own approach. The session continues with discussions in student groups of four, where they try to find an explanation for all the stations in one hypothesis. This is followed by whole class discussions about their working process and conclusions, where their final hypotheses are compared. The students then discuss briefly in their original pairs whether they would have done something differently if they were to do it again. Lastly, the session is concluded in whole class, using the model, and some suggestions for why hypotheses are valuable tools in scientific inquiry are presented. Notes on hypotheses, changes, discussions and possible improved approaches are gathered on a worksheet provided by the teacher. This worksheet is found in appendix B.

Session 3: Testing hypotheses through experiment - 80 min

The third session is also a laboratory session, where the students now design and conduct experiments to test hypotheses, see appendix A for laboratory instructions. The most general and useful hypothesis from session 2 is used as a starting point for this session, to be investigated and improved.

Intended learning outcomes of the session:

- The students can draw conclusions from data to refine hypotheses. (g)
- The students have improved their ability to conduct experiments to test hypotheses. (f)
- The students can use observations during a laboratory session to change their investigation. (f)
- The students have a better understanding of the importance of the wording of the hypothesis for how productive it is and how it can be tested. (b)

The object for the students is to investigate the starting hypothesis through experiments and then determine whether it is valid, or if and how it could be more correct or precise. The students then have one week to finish a report on the session. Their focus in the report should be on their process in carrying out experiments and drawing conclusions about the hypotheses. As assessment is important for the student focus, this is specified on the instruction for the report:
"Assessment of the report is based on the following criteria:
To what extent the experiments test the hypotheses.
How valid conclusions you are able to present based on the results of the experiments.
How well you are able to formulate a new hypothesis if your results call for a change.
There is no assessment on how similar your hypotheses are to the current theory.
The focus is on the work you do and the conclusions you draw from your own experiments and observations."

Session 4: Reflecting on own methods of scientific inquiry - 30 min

The aim of the fourth session is to use student discussions in order to focus the students on learning from their experience from session 3. Therefore, the intended learning outcomes for session 4 are essentially the same as for session 3, but cognitive instead of experience-based. In conversation with the class, different examples of good use of hypotheses and experiments are mentioned. The teacher points out important aspects of learning in relation to the purpose of session 3. This feedback is based on the reports from the students. The model of scientific inquiry is drawn again, with the addition of a research question as a guideline for investigations. Then the reports, with written feedback, are handed back to the students. The feedback on the reports is based on the assessment criteria given in the instructions. A grading, only focused on hypotheses use, is also included. On each report there is one written question for the students to discuss about their performance and strategies. This question in unique for every group and focuses on some aspect of scientific inquiry that is judged problematic or interesting in their report.

Session 5: Using hypothesis skills in a known context - 80 min

In this last laboratory session the students should try to implement what they have learnt from the previous sessions in a new context. Intended learning outcomes, apart from repetition, are:

- Students can formulate hypotheses so that they become testable by experiment (e)
- Students know how to design experiments that test hypotheses. (f)

First, there is a short introduction consisting of the most interesting conclusions from student answers from session 4. For the laboratory work, the students are asked to investigate what influences the buoyant force on objects in water, see appendix A for laboratory instruction. Students are instructed to use the experience gained in previous sessions, but now also focusing on getting as good results as possible regarding the scientific content. A working order using hypotheses and testing of hypotheses is proposed by the teacher. For this session, the students should write a full report, but with emphasis on the use of hypotheses in the planning and evaluation of experiments.

3.2 Data collection

Data was collected through various methods during the sessions, see Table 3.1, and through interviews. The interviews were conducted four weeks after the last session.

There was a brief analysis of differences in what the students actually did during the sessions. From this rudimentary classification, four students were chosen for interviews, all with different levels of performance and degree of meaningfully written reflection. Individual interviews were then conducted with each of these students. Interviews were recorded and transcribed.

Session	Method of data gathering	Main data content
All sessions	Classroom observations	Student activities and student discussions.
Session 1	Question form	Students' definitions of the word hypothesis. Repeated 9 weeks after session 5.
Session 2	Work sheet	Students' reasoning about hypotheses and their relation to observations. Ability to formulate hypotheses. Discussions about method.
Session 3	Laboratory report	Students' understanding of the assignment and reasoning about hypotheses' relation to experiments. Ability to use results to formulate new hypotheses.
Session 4	Written reflection	Students' reasoning about their performance, and the usefulness of hypotheses in scientific inquiry.
Session 5	Part of laboratory report	Applicability of new skills and ideas in a "regular" laboratory session. Ability to formulate hypotheses linking together observation, hypothesis and experiment, starting from a research question.

Table 3.1. Overview of data gathering during the different sessions.

The interviews are designed to explore the students' conceptions using questions focusing on their experiences and thoughts about the sessions as well as learning in a more general sense, before going into specific questions about concepts. Additional questions are used systematically to follow up answers by asking students to elaborate, specify or give practical examples. The interviews are individual and semi-structured. See appendix C for the interview protocol.

3.3 Data analysis

The data collection is designed to produce a rich set of quotes and results. Some of these are selected for deeper analysis. The analysis and conclusions for conceptual development are at a collective level, where individual quotes and individual development are regarded as examples. Both qualitative and quantitative analysis is used.

For all the various data collected, classifications are constructed. The classifications concern performance levels during activities, meaningfulness of reflections, and other interesting aspects that can be identified. These classifications are not determined in advance, but rather based on analysis of student quotes in the data. When analysing single interesting quotes, characteristics are identified which can be searched for in other quotes, possibly leading to new classifications. Cyclic interchange between these levels is the basic method used in most analysis.

The students' definitions of the hypothesis concept are used as the basis for a large part of the results section. The classifications for data from other sessions are not generally included in the thesis. Instead, only the conclusions are presented. Exceptions are made for particularly interesting results, where a deeper presentation is judged relevant.

The interviews are also subjected to an extensive classification process as a part of the analysis. Classifications include conceptual understanding on different levels, claimed learning, exemplified learning, self-reported learning, and differences in focus.

All quotes are translated from Swedish by the author of this thesis. The analysis and classifications are mainly done before translating.

4 RESULTS

This chapter consists of three sections that deals with RQ 1, 2 and (part of) 3 respectively. In the first section, development in students' conceptions about hypotheses is handled. Student answers from both definitions of the hypothesis concept and interviews are classified to give data on conceptual development. The second section handles general approaches to scientific inquiry. The results presented show a change towards a more reflective general approach for many students. In the third section, this change is linked to the interviewed students' answers on the guided reflection assignment of session 4, since it turns out that they are closely related.

4.1 Development in students' conceptions about hypotheses

A classification of students' conceptions is introduced, and changes in students' definitions of hypotheses are presented. Furthermore, results from the interviews regarding those conceptions are presented and related to the changes in definitions (RQ 1).

4.1.1 Classification of students' definitions of hypotheses

In this section, a classification is presented of the different views that the students express regarding the nature and role of hypotheses. The classification is based partially on the aspects of the hypothesis concept presented in the background chapter, but also derived from the different student answers collected in session 1 and through interviews. There are eight classifications, concerning the following five aspects of the hypothesis concept: Explanation included, Basis and motive, Testable by experiment, Tool for scientific inquiry, Structural role in scientific inquiry. For each classification, there is at least one student definition to exemplify.

Aspect: Explanation included

This concerns the basic explanatory nature of hypotheses. Does it include some causal relation or explanation?

Classification: Explanation or causal relation The student mentions the causal relation or explanatory nature of a hypothesis.

> "It is when you assume how something works, and write an explanation about how some

> things are related based on your assumptions."

Aspect: Basis and motive

This concerns the basis and motive for formulating a hypothesis, analysed through three classifications. What, if any, information is used to formulate the hypothesis? Is it formulated to predict the outcome of an experiment, or as a proposal about some aspect of a phenomena?

Classification: Guess The student describes the hypothesis as a guess, claim, prediction or statement without mentioning what that prediction is based upon.

> "A theory about what result you will get in an experiment/investigation. So, what you think will happen, a statement."

Classification: Informed prediction The student describes the hypothesis as a guess, claim, prediction, or statement, also describing what information to use as a basis for this statement.

> "A guess on what you think will happen for example in an experiment. The guess is based on previous knowledge."

Classification: Informed assumption The hypothesis is seen as an assumption. The student does not necessarily believe that it is correct, but rather that the hypothesis is used to claim something about an explanation, in order for investigation to be possible. The student also includes an explanation of what information to use as a basis for this assumption.

> "A hypothesis is based on an observation you have done and describes a possible causal relation between different factors."

Aspect: Testable by experiment

This concerns the specific role of hypotheses in relation to experiments. Does a hypothesis need to be testable?

Classification: Testable by experiment The student mentions that the hypothesis is to be tested, either explicitly testable by experiment, or some formulation of test "during laboratory session". Definitions that only include comparison at the end of a session does not classify as expressing "testable by experiment".

Satisfies testable by experiment:

> "It is something you formulate based on an observation. A hypothesis is then tested by experiment. A hypothesis can then be reformulated or specified depending on what your experiment shows."

> "A hypothesis is what you think you know before a laboratory session. It is often formulated as a question that you then should investigate if it is correct during the session."

Does not satisfy testable by experiment:

> "A hypothesis is what I think will happen when I perform for example a laboratory session. What I think the final result will be. In the end my hypothesis can be wrong or right. But at least I learnt something. [...]"

Aspect: Tool for scientific inquiry

This concerns the role of the hypothesis and its effects *on* other parts of scientific inquiry. Is it something taken for granted or does it influence the investigation?

Classification: A tool for scientific inquiry The student mentions that the hypothesis is a guideline for planning experiments, or that it in some other way decides or influences the investigation process.

> "A hypothesis is a question/statement from which you construct the experiment."

Aspect: Structural role in scientific inquiry

The last two classifications concern the role of the hypothesis *in* scientific inquiry. Is scientific inquiry performed in a linear or non-linear way, and can a hypothesis be changed and altered during all parts of an investigation?

Classification: Linear The student expresses that the hypothesis is something done "at the beginning" of an investigation or laboratory session. It cannot be changed or modified during or after an investigation, only possibly compared with end results.

> "When I hear the word hypothesis I think of a statement that you think can be the same as the final result you will get in the end."

Classification: Non-linear The student expresses that the hypothesis can possibly be changed during an investigation. The scientific inquiry process is non-linear, in that you can go back and fourth between different parts.

> "[...] The hypothesis can be constantly revised, as you do new experiments to strengthen what you already have thought. [...]"

> "[...] A hypothesis can also be changed afterwards, if during the experiment you gain more knowledge."

Using the classifications, the answers from the first session are analysed and compiled in Table 4.1.

Aspect	**Classification**	**Before session 1**
Explanation included	Explanation or causal relation	4
Basis and motive	Guess	6
Basis and motive	Informed prediction	7
Basis and motive	Informed assumption	1
Testable by experiment	Testable by experiment	3
Tool for scientific inquiry	A tool for scientific inquiry	2
Structural role	Linear	10
Structural role	Non-Linear	0

Table 4.1. The aspects of the hypothesis concept, and the classification of students' definitions. 17 responses are included.

Only four out of the seventeen students put as a requirement for a hypothesis to include some kind of explanation or causal relation. Many students also express the idea that a hypothesis is a guess or prediction, while few mention what the prediction is to be based upon, or how it is to be used, except for comparison with end results. Only three students mention that a hypothesis should be testable by experiment, and only two express that the hypothesis is to be used as a tool for performing scientific inquiry. In addition, more than half of the students' answers indicate that the hypothesis is seen as a step in a linear method.

On the whole, most of the students express the view that scientific inquiry is a linear schedule to follow. The formulation of a hypothesis at the start of an investigation is a well known component, but little focus is put on why it should be done. These results correspond to what Gyllenpalm describes. (Gyllenpalm 2010)

Classifications of the students' definitions from after the sequence are compiled in Table 4.2. There are 20 students in the class, but since it is conceptual development that is considered, only answers from those 17 students who answered at both occasions are included in the analysis.

Elaboration on these results in terms of conceptual development is presented in session 5.2, where also possible explanations for the development are discussed. It is important even now however, to remember that these results only regard what the students write when asked to define the hypothesis concept, and do not necessarily represent their full beliefs on all aspects of hypotheses.

Classification	Before session 1	9 weeks after last session
Explanation or causal relation	4	5
Guess	6	3
Informed prediction	7	4
Informed assumption	1	6
Testable by experiment	3	12
A tool for scientific inquiry	2	2
Linear	10	2
Non-Linear	0	7

Table 4.2. Classification of students' definitions of the hypothesis concept before first session compared to results nine weeks after session 5. The same 17 students responded on both occasions.

4.1.2 Insights expressed and identified during interviews

In this section, the results from students' definitions of the hypothesis concept are supplemented with an analysis of what students express during the interviews. The same classifications and aspects are used in this analysis, and the students can express their views on three different levels. At the most advanced level, students are able to identify differences between proposed definitions. At the second level, they explicitly express their views of an aspect. At the lowest level, their conception is only implicitly expressed. This analysis is done aspect by aspect, and at least one quote is given to exemplify each aspect. A summary of this analysis can be seen in Table 4.3.

Explanation included

Students 1 and 2 express clearly that the hypothesis should include some explanation or causal relation. Student 3 never does, but all hypotheses written or proposed by this student include some relation, so possibly it is taken for granted. Student 4 does not express this either, and does not include explanations in all hypotheses used during the sessions.

> S2: "This is a hypothesis since we propose a theory about how the relation can work"

None of the students identified this as a factor in the definitions they encountered.

Basis and motive

All four interviewed students explicitly mention that a hypothesis should be based on observations, and some of them also include theory. Since the model (See Figure 3.1) is presented to the students during the interview, this can impact their tendency to mention that theory or observations influence hypotheses.

Student 2 is the only student who identifies the basis for hypotheses as a difference between definitions presented during the interview:

> I: "Do you think that it [proposed definition of the hypothesis concept] corresponds to what you earlier [during the interview] described is included in a hypothesis?"
>
> S2: "Yes, I'd claim that but. Maybe you could have added what affects the hypothesis."

Only student 3 expresses the view that a hypothesis is an assumption that you choose in order to be able to investigate. Here after being asked to create an example of a hypothesis:

> S3: "[...] I need to believe something beforehand. Make an observation 'the ball falls to the ground when I throw it into the air'. I need to believe that something pulls it to the ground. Then I believe that it's the air pressure from high up that pushes the ball down."

Testable by experiment

Students 1 and 2 mention the necessity for the hypothesis to be testable by experiment. Student 3 does not mention it explicitly, but expresses it vaguely. Student 4 never mentions it.

Student 2, after claiming that one of the things learnt was to propose better hypotheses, and asked to explain why this is important:

> S2: "You need to be able to formulate a hypothesis before you do an experiment. Because you should test the hypothesis. If you have a hypothesis you can construct an experiment, after the hypothesis of course. You can put up an experiment without a hypothesis too, really, but you have no goal to go by. If you have a hypothesis you have a goal to test whether it's true or not. That is why you use hypotheses and that's why they are important. Because otherwise you can't conclude anything really. [...]"

This quote can also be regarded as another example of student 2 expressing the use of hypotheses as a tool for scientific inquiry.

Student 3, during discussion of the students' own proposed example of a hypothesis:

> I: "What makes it a good hypothesis?"
>
> S3: "You can imagine you see it when you do the experiment [...]"
>
> I: "And how are you supposed to use a hypothesis?"
>
> S3: "[...] You do an experiment, reflect on what happens. According to our experiment, reality looks like this. Write it as a hypothesis, can go back and work again, change."

A tool for scientific inquiry

The idea of hypotheses as a tool for scientific inquiry is expressed in some manner by all students interviewed. Student 4 confuses the concepts of hypothesis, observation and experiment to such an extent that it is hard to draw any conclusions, even though it is mentioned that the hypothesis should give some guidance for investigation. Student 1 mentions it implicitly, while students 2 and 3 express it clearly.

> I: “What makes a hypothesis a good hypothesis?”
> S2: “[...] not something about implementation really but you put it hidden. It is a bit hidden about how you can perform the investigation. [...] Explains a bit, about how you can carry out the experiment.”

The interpretation of “hidden” here, is that how to perform the investigation is not included in the formulation of the hypothesis, but a good hypothesis still provides some guideline for experimentation. But while this is interpreted as an example of the view that the hypothesis is a guideline for your experiments, it is rather vaguely formulated and not easily included in a short definition.

Only student 3 identifies this aspect during the interview, when confronted with the students’ own first definition of the hypothesis concept:

> I: “What would you like to add and change?”
> S3: “[...] That you can’t just let go of the hypothesis when you start to do the experiments.”

Structural role in scientific inquiry

Both student 1 and student 3 identify the linearity in their own previous definitions. For example, student 1 writes during session 1:

> *“A hypothesis is what you believe the result will look like after you’ve carried out the laboratory session. The hypothesis is hence written before the laboratory session.”*

And when confronted with this description during the interview, says:

> “Does not feel like you can go back and change the hypothesis. Just once, then you’re done. I would like to change... at least add... that you can change the hypothesis, go back, formulate again and see how more factors matter.”

Student 4 also mentions the non-linearity of the scientific inquiry process during the interview, but is unable to identify this in other definitions. Student 2 does not mention it at all.

Classification	Before	After	Expressed	Identified
Explanation or causal relation	4	5	2 (1)	0
Guess	6	3	0	0
Informed prediction	7	4	3	1
Informed assumption	1	6	1	0
Testable by experiment	3	12	2 (1)	0
A tool for scientific inquiry	2	2	2 (2)	1
Linear	10	2	0	0
Non-Linear	0	7	3	2

Table 4.3. Classification of students' definitions of the hypothesis concept before first session compared to results nine weeks after session 5. The same 17 students responded on both occasions. Views expressed in interviews (implicit in parentheses), and views identified by students as different in proposed definitions.

Summary on data of conceptual development

Updating Table 4.2 with the results from the interview, we get an overview over how results from student's definitions of the hypothesis concept correspond to the insights expressed and identified during the interview. See Table 4.3. For further elaboration on the implications for this, see section 5.2.1.

However, it turns out that conceptual development concerning the aspects presented in this section are not the only impacts on students' views on scientific inquiry found in this study.

4.2 Changes in general approach to scientific inquiry

This section concerns the major effects on students' general approaches to scientific inquiry (RQ 2). Firstly, a short background to this change is provided. Secondly, interview answers and some observations that are the basis for these results are presented. Thirdly, a short summary of the change and interpretation of the quotes are included.

One of the main methods for helping the students to reach meaningful conceptions about hypotheses in scientific inquiry, is the students' active reflections on the consequences of their approaches. The idea is that if you have to analyse your own method or approach, possible suggestions for improvements will be more easily incorporated as new knowledge. Relevant learning about hypotheses occur when students perceive how a change in conceptual understanding and its application would improve their performance. Such a change, if it occurs, should become visible when analysing the aspect of hypotheses as a tool for scientific inquiry.

However, it seems as if this method in itself has some consequences for what the students focus on and learn, not necessarily directly related to the aspects of the hypothesis concept presented in the previous section. During the interviews, when asked about what they have learnt during the sessions, the students do not mainly talk about the specifics of the hypothesis concept. Rather, they mention a change towards a more reflective view of, and methods for, scientific inquiry. This unpredicted change in general approach is presented by student 4, 3 and 1. Here, extensive quotes from interviews are presented, to give the interested reader a more complete understanding of what this change consists of.

> I: "Do you have anything specific that you have learnt during these sessions we've had?"
> S4: "Yes, Most importantly I have probably developed my way of thinking during laboratory sessions. To think many times, propose many hypotheses and many questions that I should answer through this experiment that I do. I have to say it's been very interesting to gain the opportunity to learn all this. In this way I've had the opportunity to improve how I do things."
> I: "Can you give any examples of what you have improved?"
> S4: [long silence] "hmm, maybe it was [session 5] there. We saw it, we did many different tests. We try once, felt that this was not reasonable. We test again and this time we maybe do it differently, to get a more reasonable answer. And that, is something I *never* do usually, maybe one can be a bit lazy in that way. We maybe did it once and then thought it is enough, like, good enough. [...]"
> S4 (later during the interview): "That is a large part of what I've learnt during your time here, to be reflective"
> I: "Why is it important to reflect on things?"
> S4: "Better answers, question your own actions, gets better next time you do a laboratory session".

Student 3 is more specific, and also mentions this general learning as the very first thing during the interview:

> I: (at the very beginning of the interview) "Well, first I thought that you could tell me something about your view of what the sessions I've held with you have been about? Some general impression?"
> S3: "In that case I would say like, how you could develop your own thinking. Like, from the point where you get an assignment to like find out what you should do, and from that create an impression of what you learn from the laboratory session that you do. So that you like... Normally, you just do something and then you sit down to think. Now it's more like you think before, so what you do, you can really conclude something from." [...]
> I: (about ten minutes later) "Is there anything specific you can think of that you learnt from these sessions?"
> S3: "Well, mostly to think of what you are doing during the time you perform your work. Have done it before, but maybe not in the same manner. [...] But this with how you act to get as good results as possible from the experiments."
> I: "Can you give an example...?"
> S3: [long example about details in a measurement session 5, where they failed to make a measurement needed because they took some theory for granted]
> I: "But if you think... [pause] You say that you learnt how to think in these cases, methods of thinking and examining. Can you give examples of those, what is the content of that learning?"
> S3: "But that, before you start something, even if you have an idea like, this is what I would like to test, so maybe you stop to think, 'What is it I would like to

> see when I test this?'. And not, I test something, I know fairly well what the result should be, but I just go on. But instead this, with some thought before you start."
> I: "And what made you think about this, what made you learn it?"
> S3: "Probably that it's been difficult to be able to say why I've seen something. Because I knew I've seen it, but how did I conclude that I saw it? It's like facts that I could notice, but since I did not think before I can't say that this was what I tested in the experiment."
> I: "So you've learnt this by...?"
> S3: "The experiments not turning out very good"

This description is in line with the laboratory report for session three, where student 3's group performed a large number of different experiments, but the conclusions were unclear. It is also something actively highlighted to these students through the question on session 4, see section 4.3. The description includes many key parts of how the use of hypotheses is meant to contribute in scientific inquiry. So while student 3 never mentions hypotheses during these parts of the interview, the student's answers clearly imply that the sought development is achieved in a more general sense.

For student 1, the more reflective approach is closely linked to the search for new hypotheses as well as the creation of experiments that test the hypothesis in different ways. In this way, student 1 relates this learning more closely to the specific ideas on hypotheses presented during the sessions.

> I: "Is it something specific from all these sessions that you think you've learnt?"
> S1: "Yes, that's definitely to formulate a hypothesis, and then test if it is correct, then reflect on what you could change in the hypothesis, see how different factors can affect it, test with different materials. [...] "
> I: "OK, so this is quite general, can you mention some specific event that made you learn this?"
> S1: "[long description of session 3 experiment, with specific example that disproved the hypothesis...] to think outside the obvious, to think in one more step. For example, we go outside the hypothesis and reflect more."
> I: "How did you come to think of that?"
> S1: "We wanted to be able to disprove it [the hypothesis] in some way, using the laboratory session."
> I: "What made you want to do that?"
> S1: "Thought of this picture [of the model, discussed some minutes before in the interview], to go back to the hypothesis. [...]"
> S1: "It is important that you are creative and try to test new things in open laboratory sessions." [...]

Later during the interview, student 1 also gives examples of this approach in session 5. Students 1, 3 and 4 are all able to present actions where this claimed learning did matter. In contrast to student 3 however, students 1 and 4 are unable to present solid ideas about what caused this learning.

The focuses of these three students are slightly different. Student 4 is quite general in the description of reflection, and is mainly stating that it is good to think more and not be satisfied so easily. Student 3 is somewhat more precise, stating that one should be aware at all times and as far as possible the reason of doing things in a specific way, what they will lead to, and which questions they will answer. Student 1 links the reflection mostly to test the hypothesis significantly, and being able to come up with many hypotheses and explanations. However, they all express something that was not in the intended learning outcomes, but actually the very purpose, for the sequence. That is, becoming aware of your own approach to scientific inquiry, which, at least for student 1 and 4, is used to consciously improve performance.

There is no quantitative data available for comparison, as was done with the definitions of the hypothesis concept above. What can be said is that three out of four students interviewed, with large differences in performance on assignments, clearly present this more reflective view as their main learning from the sequence. Moreover they did so before being asked specifically about reflection or general approaches to scientific inquiry. As can be seen in the next session, it turns out that the answers to the reflection assignment during session 4 corresponds very closely to this learning.

4.3 An activity's contribution to changes in general approach

This section presents a partial answer to RQ 3, on causes for change in general approach. The reflection activity during session 4 turned out to be closely related to what the interviewed students mentioned about changes in general approaches to scientific inquiry. The section includes examples of reflection questions and answers for two students in order to exemplify this point, further strengthened by quotes from interviews.

During session 4, students work in the same groups of two as in session 3, and each group recieves a specific question about their approach, performance, and implications from this, based on the laboratory reports from session 3. Being the most significant guided reflection of the sequence, session 4 provides the main possibility for students to use reflection to learn about the scientific inquiry process. Three of the interviewed students, 1, 3 and 4, wrote meaningful reflections to a varying degree on this session. When we arrived at the question about that reflection during the interview, all of them had already mentioned central parts in their answer in session 4 as a major learning outcome for the sequence as a whole. I exemplify with students 3 and 1 below.

> Question session 4:
> "How did you decide what experiments to perform? Did you decide everything from the beginning or did you use new ideas and thoughts that appeared while performing the experiments? Answer the question and also mention if you can think of any advantages or disadvantages with your approach."
> Written answer (S3):
> "[...] The laboratory session evolved during the time we performed it. The first thought was only to test the starting hypothesis, but we came up with new theories to test all the time. Advantages of our way of working were that the experiments became relatively extensive since we were always prepared to evolve our testing. [...]"

> "The disadvantages with our way of working was that it was not that structured since we developed the basic thought all the time. This meant we were not in full control of what actually occurred. If we would have had more structure it might have been easier to develop the hypothesis correctly afterwards."

> I: (Interview, after letting the student read the answer given on session 4): "What do you see as the most important learning here?"
>
> S3: "About like what I said before. To understand what to do before you start. And that the work like, sometimes it could be good to just start working, and reflect afterwards, but that you keep track of what you are doing and why while you're doing it, and not get carried away."
>
> I: "Do you feel like you used that thought during the session about buoyant force?"
>
> S3: "Yes, I think that we thought a lot more before we started. Even if we missed something, we had a plan. We should test four weights in water, oil, and denaturated alcohol, and we did all this. Then maybe if we would have had a three hour lecture, we would have been able to structure even more and discover that we could try this and that also. But from the conditions we did a lot better compared to earlier."

I share the conclusion that student 3's group did a lot better on session 5 than session 3. Especially, they were more sucessful in drawing conclusions from their experimental results. More importantly, we see clearly how the written answer on session 4 corresponds to what the student identifies as central for the sequence, and what the student claims to have learnt. See section 4.2 above.

Student 1 mentions mostly the importance of testing hypotheses in many different ways, and speculating about possible factors of influence.

> Question session 4:
> "Your fourth experiment was clearly the most interesting, how did you get the idea to try that specific experiment? Is there anything in your way of working that you can keep for future open investigations that makes you find the interesting questions and experiments again?"
>
> Answer (S1):
> "After experiment three we arrived at the conclusion that for the wheel to be completely still, the weights must be placed on the corresponding place on the other side, that is to say, 180 degrees away. After the thought about the different angles we did test 4. What we keep from this session is to try speculating about different possible factors that might matter."

This answer is not nearly as clear as student 3's above, and hardly classifies as meaningful in itself. Still, the part about speculation about different factors was mentioned and elaborated upon by the student as a central part of the main learning. When arriving at the question about this session during the interview, the student identified that the key words were "speculate about different possible factors" and agreed that it was already discussed enough.

For student 4 as well, the answer on session 4 corresponds to the claimed learning from all sessions, but it is not entirely consistent with some comments during other parts of the interview, mainly because of confused conceptions.

From the previous section, it is clear that three out of four students presented some improvement of their general ability to perform and think about scientific inquiry as their central learning from the sequence. The contents of these claims are different for different students, but for these three students, they correspond closely to their answers on reflection questions during session 4. All these students are able to exemplify with occasions when this learning affected their behaviour. Student 3 is also able to present an idea of what caused it, namely the failure to satisfactory manage a laboratory session.

Naturally, this assignment does not stand detached from everything else, neither is it the only thing that the students mention as meaningful during the interviews. An evaluation of the three types of teaching and learning activities is presented in the discussion section 5.1 next.

5 DISCUSSION

In this chapter, a discussion is presented with conclusions on causes for learning and conceptual development. In the first section, a closer evaluation of the different types of teaching activities and learning is presented, where their impact is assessed and improvements suggested (RQ 3,4). In the second section, the five identified aspects of the hypothesis concept are considered. Firstly, conclusions on actual conceptual development from definitions and interviews are presented (RQ 1). Secondly, conceptual development for each aspect is compared to where the aspects have been present in the different types of teaching and learning activities (RQ 3). In the third section of this chapter, the combined conclusions about causes for learning and conceptual development are presented (RQ 3).

5.1 The different types of teaching and learning activities

In this section, the three types of activities (see Figure 2.1) are evaluated separately. With analysis of observations and interviews, conclusions are made about causes for learning (RQ 3) and implications for teaching (RQ 4). Important conclusions and implications for teaching are written in *italics*, except in the summary.

5.1.1 Direct instruction and the model of scientific inquiry

The model of scientific inquiry (see Figure 3.1) is used as a framework for most direct instruction about scientific inquiry when instructing the whole class. Most significant direct instruction occur during session 1, but it is also included in sessions 2-4 to a varying degree at start or end. In this section, I assess the impact of the direct instruction, mainly through interview answers.

When asked directly, all four students interviewed claim to have used the model of scientific inquiry (described in section 3.1.1) in their further work with laboratory sessions. When asked to describe the model, student 1 mainly identifies the non-linearity, while student 2 talks only about the theory dependence of all other parts. These are examples of specific aspects of the model. Student 3 gives an excellent recollection of the main points of the model, except the role of the research question. Student 4 gives a poor description, mainly because of confusion about the different concepts involved. Students 1 and 3 can give examples of when they claim to have used the model to improve, or at least better understand, their chosen methods for scientific inquiry.

Only student 4 mentions session 1 at all. The student describes the demonstration of how to use hypotheses in scientific inquiry as interesting and thought-provoking. The recollection of the session is mainly correct.

During session 5, only about half of the students' experiments are clearly constructed to test precisely the hypotheses formulated. This was one of the most pressing points for some of the early direct instruction, but was not recurring in discussions during the following sessions, even though it was seen as a central point and often included in feedback. Despite the increased awareness that hypotheses need to be testable by experiment, the majority of the students do not actually apply this.

In conclusion, it seems like the direct instruction can have a large impact, but it is not at all certain that the students focus on exactly that which the teacher includes in direct instruction. *Rather, the impact of direct instruction for any one student is dependent on what the individual experiences during the other teaching and learning activities, and also on the student's previous conceptions.* This is evident from the different focuses the students express with regard to the model and other direct instruction. This conclusion is also strengthened by the fact that the students mention the direct instruction as central only to a small degree, but clearly present some ideas that relates directly to what is said and written. *Taking a constructivist perspective, this is not surprising, but the degree of variation among the students implies that there is room for some improvement in linking the main ideas of the direct instruction to the students' understanding and experience* (Säljö 2010).

Among the students interviewed, those focusing on what they are intended to learn from the sessions have a higher tendency to change their general approach to scientific inquiry, and a somewhat higher tendency to improve their conceptions, than those who focus on specific content and assignments.

5.1.2 Use of hypotheses during scientific inquiry activities

The major directed scientific inquiry activities occur in session 2 and 3, while in session 5 it is more up to the students to choose their methods and approaches.

In the second session, the environment and activities for the students are quite strictly directed. Time frames are short, the questions determine in which way students can answer, and the assignments are designed to engage students in activities of formulation, reformulation, discussion and comparison of hypotheses. Knowing this, it is not surprising to see the results from the worksheets. All student groups have formulated valid hypotheses for all, or all except one, question. They also to a high degree mention what observations they have used for building their hypotheses, and some draw on previous experience and knowledge.

Throughout the session, students discuss and compare the hypotheses in a way that challenges the idea that a hypothesis is only something to propose before making an investigation. In addition to having hypotheses as a final goal rather than a starting guess, the students also get to experience how to construct a general hypothesis from different observations and experiences and several previous hypotheses. The discussion and comparison between the groups at the end of the session also managed to focus students on the different qualities and degrees of generalisation of different hypotheses. *Here, the teacher interaction was essential in pointing out differences and similarities.*

For the third session, the given hypothesis and the instruction to test it through experiments made the hypothesis use more familiar to the students. Here, the focus is mainly on the link between hypothesis and experiment. All students managed to conduct experiments and evaluate the starting hypothesis satisfactorily. They seemed fairly confident in their work, which indicates that session 3 is more similar to what they are used to in laboratory settings. There were nine groups. Five out of these managed to arrive at qualitatively new hypotheses. Six groups held some kind of discussion about the validity of their experiments and the hypothesis, as well as the reliability of their conclusions.

All in all, it is evident from the results that with the right planning, students with misconceptions about hypotheses can be guided to use them in new ways. During session 2 and 3, hypotheses were used as a basis for discussion of phenomena and possible explanations. They were goals in themselves, and they were not only guidelines for experiments but also the results of them. Furthermore, the wording of the assignments ensured that the hypotheses contained some sort of explanation. During session 5, few students use ideas and approaches from the previous sessions. There are some exceptions though; a few groups did use ideas from the sequence. Some students even had a better approach and use of hypotheses than during session 3.

5.1.3 Guided reflection assignments

In this section, the reflection assignments from session 2 and session 4 are evaluated, with discussion of the impacts from the respective activities. The major correlation between session 4 and changes in general approach to scientific inquiry is presented above in section 4.3. At the end of this section, a summary with comparison of the respective assignments is presented.

Session 2

In session 2, there are two assignments designed explicitly for student reflection. The first assignment is to observe another group working on a station that the students just visited themselves, and the other is a reflection about the whole session:

> 1: "Observe how another group works at the station, what are the differences?" and "Which advantages and disadvantages are there compared to your approach?"
> 2: "If you were to redo the session, what would you have done differently in how you worked with formulation of hypotheses?"

Many students noted differences in *details* in how they performed the assignment at the station, but few of those observations led to any reasoning about how the differences affected the outcome. Examples of differences in details are differences in weights used, or how sensitive the instruments were. Of the students that noted differences in *approach* or *previous theoretical knowledge*, meaningful reflection was much more frequent. The most interesting insights were written by students who noted differences in approach. Differences in approach were qualitatively different materials used, substantially more measurements, or entirely different methods of investigating the phenomena. For example, students noted differences in how certain they could be of their respective hypotheses, or that arrival at a similar conclusion can be based either on many observations or few observations but fitting into a previously known theory.

It seems that differences in details are easiest to note, but also yields little, which is why the teacher should try to steer the attention of the students to differences in approach.

Answering the question at the end of the session, more than half of the groups wrote something meaningful about their approach, implying that they thought they would have done something qualitatively different. Examples are: to make more varied manipulations in order to get more observations, or to try to keep in mind and examine connections between different but similar phenomena. One group also noted the need of trying to explain, not just describe. There were also many comments on circumstances outside the students' control, like lack of time, as well as nondescript claims to do "better", "with less error", or "longer". Some students also claimed to be satisfied with their performance and hence proposed no improvements.

From this can be gathered that the purposes of the assignments, namely to discuss which approaches may be efficient in formulating meaningful hypotheses, need to be expressed clearly to the students. This would be done in order to reach those who misinterpreted the question or focused on the wrong subjects on both assignments, to improve their opportunities to learn. It could also be helpful for those satisfied with their performance. It could help them highlight for themselves what made them content with their performance, thus being able to repeat and refine their tactic.

At a first glance, these results seems encouraging for both assignments, since such simple questions had the majority of the students coming up with proposals that probably would have improved their performance. It turns out, however, that the interviews give a different impression.

Regarding the first assignment, most students could recall their lines of reasoning and give examples of how it had been useful. Student 1 had not written any answer at all on the reflection question, and student 2 had a very short answer that did not classify as meaningful. Despite this, they both claimed learning from this assignment that is in line with what they did and wrote on the session. *This is interesting, since it implies that even if the students did not write the reflection in a manner* *that classified as meaningful, it may have been valuable anyway.*

As regards the second assignment, none of the interviewed students could give any example of what they gained from it. All students claim general insights, but when asked to give examples, they could not. Student 2 even constructs an answer that is contradictory to the answer given on the written reflection. My interpretation is that they construct an intellectual picture of what this kind of assignment could give, and then attempt to apply some general knowledge from elsewhere (from sessions or from other contexts) to fit into the question. This does not mean that the reflection was worthless, but that their claimed insights can not be regarded as originating with this specific reflection.

The second assignment seems to have been too loosely defined for any insights to stay with the students for long. *Perhaps with a more clearly defined purpose of the assignment this could be improved, in combination with a more specified question that steers the students away from circumstantial aspects.*

Neither the direct instruction of the first session nor the practical examples and reflections of the second are certain to convince the student that the new way of regarding hypotheses use as non-linear is valid. This can be seen from an answer to question 2, at the end of the session:

> "We did our hypotheses after we did the laboratory work, it should be the other way around. But in this case we did not know so much about how to perform the laboratory session so we had to formulate a hypothesis after we were done with the session. To see what the session told us. [...]"

Session 4

In session 4, students answer reflection questions about their own laboratory reports from session 3 that are handed back to them with grading and comments on the same occasion. Each group answers a specific question about something in their approach that was judged problematic or interesting.

Four of the nine participating groups clearly communicate new insights from the laboratory session and reflections. The main issues brought up by the students are advantages and disadvantages of different approaches. They argue, from different points of views, that routine measurements do not challenge a given hypothesis essentially. A more unstructured search, on the other hand, could produce many interesting observations but also make it more difficult to keep track of all the things you are doing and therefore also difficult to formulate clear conclusions. Student 3 and student 4 belong to this classification. The answer of student 1's group did not classify as clear, but it still had a core of qualitative insight about approaches to scientific inquiry.

Two groups, including the group of student 2, made reflections as they were asked to, but without any qualitative insights about the scientific inquiry process. No question was asked to student 2 during the interview about this assignment, so nothing can be said about the implications for a student whose answer did not classify as meaningful.

Two groups failed to produce valid reflections altogether. For one of the groups, it depended on a missing group members. The other group misinterpreted, or completely missed the point of, the reflection question. Here, the fact that I did not talk to the group during the session clearly had a severe impact on the students' ability to make meaningful reflections. When discussed at a later point, the students quickly understood the purpose of the question, but there were not enough time to repeat the assignment.

In summary, the assignment was potentially very valuable to slightly more than half the students. It is difficult to draw conclusions about the rest of the students, except that the design of the assignment makes it vulnerable to factors like student attendance, and possibility to understand the questions. *Thus, teacher feedback during the session is essential.*

These results imply that the guided and personal reflection, used to link the practice of the laboratory work to the theoretical discussions on hypotheses, have a large impact on what the students actually remember and focus on. The purpose of the assignment, namely to lead students to criticise and develop, or at least become more aware of, their methods and approaches, is fulfilled for many. It is not certain that this proves that session 4 caused this learning for all students, but the content of the reflections are at the very least correlated to what the students remember as learning outcomes.

For student 3 specifically, *there is also a strong suggestion that the failure in session 3, discussed during session 4, was what made the learning possible. It is probable that this learning was further helped by the fact that I chose group specific questions on performance in session 3, which focused on possible areas of improvement.*

That session 4 was valuable for those who made meaningful reflections is also implied by the fact that all such students that were interviewed had different learning focuses in their reflections. Also, all of them presented this as separate learning outcomes from the sequence as a whole, before any question about session 4 was introduced on the interview.

The reflection assignment in session 4 is the activity that most clearly linked the different types of teaching and learning activities to each other. These results strongly indicate the value of this kind of assignment, granted that the teacher can find time to adapt it to all students.

Summary

While almost all the students made meaningful reflections at some point, only just above half of the students wrote down meaningful reflections at any given opportunity. Sometimes, as became especially evident in session 4, the oral discussion with the teacher during reflection was critical for the students to understand and get to the core of the question. Furthermore, there was no clear link between how well the students performed on the specific tasks and their ability to reflect in a meaningful manner.

Based on the four students interviewed, those performing better on the reflection assignments have a greater tendency to improve both their conceptual understanding and their general approach. But even students who do not obviously reflect in a meaningful manner and tend to focus on scientific content and performance only can gain insights about the hypothesis concept and its use.

Out of the three specific guided reflection activities discussed, session 4 was clearly most fruitful. The assignments in session 2 gave rise to some initially meaningful reflection among some students, but for the second assignment, few seem to remember it a few weeks later. When analysing the assignments, some differences and similarities can be identified. Firstly, all reflection assignments aim to focus the students on the more abstract level, about their methods and approaches. The reflection assignment at the end of session 2 concerns the abstract level only, unless the students themselves link to the practical work performed. The other two assignments relate directly to practical work performed by the student and are intended to raise awareness about abstract conceptions from there. The latter proved to be more efficient. Secondly, session four is heavily built on feedback, identifying interesting misconceptions or areas of improvement for the students, while the other two assignments do not include any planned feedback. Thirdly, session 4 includes general feedback and direct instruction relating to theoretical ideas of scientific inquiry, thus giving the students an opportunity to apply the new ideas in evaluation of their own performance. Of course, the comparison is a bit unbalanced, since session four was 30 minutes long and demanded well over three hours' preparation writing feedback and questions, while the other assignments lasted about five minutes each.

5.2 Aspects of the hypothesis concept

In this section, an analysis of the development of the students' conceptions is presented. Firstly, the extent of actual conceptual development is analysed, for each of the identified aspects of the hypothesis concept separately (RQ 1). Secondly, an overview is given of where the different aspects have been visible in the sequence. Lastly, this overview is analysed, and conclusions drawn regarding causes for learning and conceptual development (RQ3).

5.2.1 Elaboration on conceptual development

This section presents conclusions for the actual conceptual development that can be seen compared to before the sequence. This provides a more thorough answer to RQ 1 than previously presented. It is important to remember that conclusions on conceptual development are considered at a collective level, even when individual interview answers are used as examples of this development.

Here, a short introduction of methods used to draw conclusions from the data is presented. When considering the results compiled in Table 4.3, it is important to note the different implications for conceptual development that can be seen in different types of answers. Students' definitions represent what they come to think of when they receive a direct question on what a hypothesis is. The defenitions do not represent the student's entire conceptual understanding. Expressing a view of hypotheses is a stronger indication for conceptual *understanding*, since the student actually uses it in relation to discussion about scientific inquiry. When judging conceptual *development*, however, these answers do not give strong indications by themselves, since there are no interview results to compare with from before the sequence. This is especially true for implicitly expressed views of aspects of hypotheses, since those views are unlikely to appear on either of the definition questions. The strongest suggestion for conceptual understanding is when students are able to identify differences between suggested definitions of the hypothesis concept. When related to their own previous definition of the hypothesis concept, it is also a strong indication for conceptual development for that student.

A clear result is the shift of students' views toward a conception where hypotheses are used in a non-linear way. There is a large shift in the definition classification, and it is both mentioned and identified as a difference during many interviews. I regard this as an actual conceptual development for many students compared to before the sequence.

In students' definitions, there is also a clear shift towards more awareness of the need for a hypothesis to be testable by experiment. This is also mentioned by most interviewed students, though none of them identified it as a difference between proposed definitions of the hypothesis concept. Still, it seems likely that there is a general conceptual development here as well.

The description of the hypothesis as a tool for scientific inquiry on the other hand, has not increased at all in hypothesis definitions. This is despite the fact that all (!) students interviewed mention this directly or indirectly as a purpose for hypotheses. I believe that there is a general awareness of the hypothesis as a tool, but it is not easy to determine the extent to which it was present before the sequence. There is, though, at the very least, anecdotal evidence for concept change of this aspect. I would guess that it is an aspect which is difficult for students to capture when asked to present a short definition, and that there might be conceptual development for many students that is not visible in the definitions.

The thoughts about basis and motive in formulation of hypotheses has shifted somewhat towards more informed views. Even if the change in classification of definitions is moderate, all interviewed students to some extent mentioned the need for hypotheses to be based on observations and/or previous experiments and theory. The idea that a hypothesis is an assumption rather than a prediction clearly has increased support. This implies conceptual development, as the idea was barely present before the sequence, and was introduced through the direct instruction of session 1.

Regarding hypotheses including explanations or causal relations, there are no reliable differences in the student's definitions. Even though many students identify this as important during the interviews, I see no evidence in numbers or in quotes that awareness about this aspect has increased.

It becomes evident from the quote below that at least some students are of the opinion that their concept of hypothesis has changed. The quote is from the interview, when student 3 was confronted with the student's own previous hypothesis definition:

> Definition S3: "A hypothesis is what you think you know before a laboratory session. It is often formulated as a question that you then should find out whether it's correct during the session."
>
> Comment S3: "This is the description used in upper compulsory school [age 13-15] about hypotheses. Because we did not talk a lot about hypotheses here before, and when you went to grade nine [age 15, one year ago] it was like, before the session, you got to propose what will happen that's it. It was about that you learnt about hypotheses then. Then that it is a rather large difference in what you believe now probably only has to do with the fact that you learn new stuff all the time."

This quote is completely in line with Gyllenpalm's investigation of the Swedish secondary school education. There is little talk about hypotheses, and they are often used in the way that this student describes (Gyllenpalm 2010). The student seems to think that these sessions helped with that misconception, and the last sentence indicates that it is seen as a natural part of the education, not something 'special' from a detached intervention.

Hence I conclude that there are relevant development in students' conceptions regarding aspects of non-linearity, and the need for hypotheses to be testable by experiment. The results also indicate that there are smaller but relevant impacts on conceptions about the basis and motive for hypotheses and the hypothesis as a tool for scientific inquiry. However, as regards the awareness of the explanatory nature of the hypothesis, there is no evidence that the students' views changed during the sequence. See the first two columns of Table 5.2 for an overview.

An interesting observation when analysing students' definitions is that many students regard the concept of hypothesis only in the school context. In their answers, the laboratory session is the arena for scientific inquiry and thus the definitions of the hypothesis concept regards laboratory sessions. Even among those who did not directly express the school context, traces of it can be seen in some answers. There was a small decrease in the number of answers directly assuming school context, but not enough to conclude any change. That students consider only the school context could influence which conceptions are valid for them, and how conceptual development should best be promoted. However, such an analysis is outside the scope of this thesis, and hence referred to future research.

5.2.2 Correlation between session design and conceptual development

Given the five main aspects of the hypothesis concept identified, and the three major types of teaching and learning activities, what correlations can be identified between these? The types of teaching and learning activities are: direct instruction, activities of scientific inquiry, and guided reflection activities, as presented in Figure 2.1. This section includes a recollection of the different aspects of the hypothesis concept, and an account for how these aspects are present during the different types of activities. This analysis was done after the sequence was finished, and thus based on what actually happened, not what was planned. This section contributes to the answer of RQ 3, about causes for conceptual development.

That a hypothesis needs to contain an explanation or causal relation is mentioned briefly in session 1, but is not apparent from the model. It is built into session 2 through the way the questions are asked, but it is not necessarily visible to the students that all their answers actually contained an explanation. Since all students did this automatically for session 2 and 3, there was no opportunity for feedback either. It was not part of any reflection.

That the basis for hypotheses should be observations, theory, and sometimes previous experiments is very clear from the model. It is a central and visible part of much direct instruction about scientific inquiry in session 1 and 2, but becomes less common during the later sessions. That you should base your hypotheses on observations and experiments is very evident in the activity in session 2. It is also partly present in session 3, since the students are asked to formulate a new hypothesis based on experiments and new observations. The idea that hypotheses should be formulated as assumptions rather than predictions is a central part of instruction during session 1, but is not mentioned explicitly after that. No reflection focuses specifically on this aspect of the concept.

That hypotheses should be testable by experiment is mentioned during much of the direct instruction, especially through feedback to the students. It is not visible in the model. The aspect is one of the main focuses of the activity in session 3. It is also present in some reflection assignments, depending on what the students chose to focus on and the exact content of their individual reflection question at session 4.

The hypothesis as a tool for scientific inquiry is a theme present in session 1, as motivating the explicit teaching about hypotheses. It is not mentioned in whole class again, but expressed in some feedback, especially related to session 3. It can be read into the model, but is not clearly visible there. Its presence in activities was heavily dependent on student use, and purposefully included only in session 2. However, it was the main focus of most of the guided reflection activities.

The non-linearity of scientific inquiry, and hence the structural role of the hypothesis, is very visible in the model, and thus in all direct instruction to whole class. It is also central in activities during session 2 and 3. Some students reflected on it, but it is not a central part of the guided reflection design.

To summarize, the correlations are gathered in Table 5.2. It is not possible to say that a specific assignment had a specific effect. Rather it is the interaction that determines how effective the education is for the students' learning.

Aspects	**Conceptual development**	**Activities**	**Reflections**	**Direct instruction**
Explanation included	No evidence	Built into sessions 2 and 3, not visible	No	some in session 1
Basis and motive	Probably	Yes, especially session 2	Not necessarily, very rare	Yes, sessions 1 and 2, model
Testable by experiment	Clearly	Yes, sessions 2 and 3	Possibly, but only for some	Yes, sessions 1, 2 and 4, feedback
Tool for scientific inquiry	Possibly	In session 2, otherwise dependent on students	Yes! A main part of reflections	In sessions 1 and 2, possibly in model, but not visible
Structural role	Clearly	Yes, repeatedly	Possibly, but only for some	Yes, repeatedly, in model

Table 5.2. Overview of the correlation between where aspects are included in the three different types of teaching and learning activities, and the conceptual development regarding each of those aspects of the hypothesis concept.

From Table 5.2, it would seem that the appearance of an aspect of the hypothesis concept in many types of activities has a large impact on the tendency for students to change their conceptions. Furthermore, it is necessary for the new aspects to somehow be made visible to the students. This is either done by the teacher expressing them clearly and directly, linking them to the student's experience, or by including them as an easily identified part of the model of scientific inquiry used during the sessions. For visibility, the use of extensive feedback is of great importance to connect the different teaching and learning activities and make students aware of their misconceptions.

Conceptional development about the hypothesis as a tool for scientific inquiry is partially an exception. Despite lots of reflection assignments and inclusion in both instruction and activity, this aspect is not identified as central by many students, even if the interviews provide evidence that the students are familiar with the idea. I believe that this is an inherently more difficult property of the hypothesis concept to express than many of the others. In addition, it is an aspect that can be difficult for a student to observe during activities of scientific inquiry. For example, the structural role, or being testable by experiment, are aspects where changes have a more visible impact in how scientific inquiry is performed. The idea that the hypothesis is a tool to build your experiments from has more to do with how you think about the inquiry at hand than the exact visible performance.

Regarding the notion of hypotheses including causal relations, there is little improvement, despite it being one of the aspects clearly identified and included in the sequence from the very beginning. In retrospect, I can identify some problems that may have contributed to this deficiency. Even though the aspect is present in the activities of both sessions 2 and 3, the students never need to reflect on the matter. They conduct the assignments, and use the aspect in their hypotheses, but never need to recognise it. The aspect is also present during direct instruction in session 1, but is not brought up again, and is not visible in the model. This is the classical mistake described by (Abrahams and Millar 2008). While the sought content is included in the laboratory design so that the students use it, the set-up fails to lead the students to think actively about that content.

However, as with the aspect of the basis of hypotheses, direct instruction in combination with the practical activities can have effect, even if there are no explicit assignments for reflection. This aspect is only slightly more present than that a hypothesis should include an explanation, but is much more visible, both in the model and the design of session 2.

5.3 Conclusions on causes for learning

In this section, conclusions from the discussions on conceptual development and causes for learning are presented (RQ3).

From the analysis of Table 5.2, I conclude that it is possible to achieve changes in students' conceptions about some aspects of the hypothesis concept and its use in scientific inquiry. It can be done through a well-managed interaction between theory and practical activities, combined with opportunities for reflection and feedback. Even without specific reflection assignments, conceptual development can occur if the aspect is visible and direct instruction and scientific inquiry activities are properly interrelated. Without interaction between the different types of activities, and without specific effort to make the content discernible to the students, there is little learning about an aspect, even if it is included separately in both laboratory activities and direct instruction. This is in line with the ideas of constructive alignment

(Biggs 1996).

The direct instruction is important, and most students claim that the presented model of scientific inquiry is useful for understanding the scientific inquiry process. It is clear that the degree of influence on the students from direct instruction varies a lot, depending on what the students happen to focus on. This in turn depends heavily on the student's experiences from the other teaching and learning activities, as well as the students' previous conceptions.

The scientific inquiry activities are the main basis for relating the concepts and discussions to content. Teacher interaction is essential at some key points for making those relations visible to the students. Also, the design helps the students to use hypotheses in ways that include most of the sought aspects. However, some of these aspects never become visible to the students, due to the lack of the interaction with other types of activities.

The assignments for guided reflection have proven to facilitate for students to understand in a larger context that which they have done during practical activities. Thus, reflections work as links between the ideas presented by the teacher, and the practical activity. This, however, is not valid if the reflections becomes too general, and it is weakened further if the purpose is unclear to the students. Greatest influence comes from individually adapted and feedback-rich reflection assignments, linked to previous practical work, such as session 4. Asking students to motivate and account for their methods and choices, had the effect of leading students to reflect more on their chosen approach to scientific inquiry in general. Here, the reflection activities were the key contributor, even though it was the link to practical activities of scientific inquiry that made it possible.

Conceptions and even general approaches can evidently be improved, but not equally so for all students. Focus and performance can influence the level of development, but all students interviewed show reliable progress in either general approaches to scientific inquiry or conceptual understanding of hypotheses, or both. This suggests that the sequence can be meaningful to students with very different focus and performance levels.

In general, many ideas presented in the background chapter seem to correspond to my conclusions:

- The value of combining mutually interacting types of activities (Abd-El-Khalick and Lederman 2000).
- The importance of feedback for making purpose and goals understood, and the potentially large impact of feedback on processes and approaches (Hattie and Timperley 2007).
- The weak learning results from aspects only covered by scientific inquiry activities, without any teacher interaction or reflection that makes those aspects visible (Abrahams and Millar 2008, Schwartz *et al.* 2004, Hodson 1996).

The crux is the implementation and practical planning. While the sequence functioned to improve some aspects of the students' conceptions of hypotheses by making them visible in many types of activities, it failed for others, see Table 5.2.

6 CONCLUSIONS

In the first section of this chapter, the main results, methods and conclusions of this thesis are briefly summarised. In the second section, recommendations for teaching are presented. In the third section, some suggestions for future research are proposed.

6.1 Summary

This thesis is a contribution to the discussion of how to teach *about* scientific inquiry, and specifically, the hypothesis concept. Previous research shows that misconceptions about the hypothesis concept are common for students in the Swedish upper secondary shool, and that these misconceptions can stem from the non-scientific use of the word hypothesis in the school context (Gyllenpalm 2010). To deal with this problem, a sequence of sessions has been developed, with the aim of helping the students develop a better understanding of the concept of hypothesis, and why it is useful in scientific inquiry. The sequence consists of five sessions, combining three types of teaching and learning activities, direct instruction, activities of scientific inquiry, and guided reflection assignments, see Figure 2.1 for details.

From these sessions, data is gathered on the students' performance and conceptions. This is done through students' answers on various written assignments and laboratory reports, as well as through classroom observations. After the sequence, individual interviews are conducted with four students. Analysis of conceptual development and causes for learning is mainly done by working with classifications of the students' answers.

Research questions (RQ) :

1 What development in students' conceptions of hypotheses can be seen after the sequence?

2 Were there any other major effects on students' general approaches to scientific inquiry?

3 What can be said about causes for conceptual development and changes in general approach?

4 How can meaningful explicit teaching about the hypothesis concept and its use in scientific inquiry be designed?

RQ 1: Conceptions about five major aspects of the hypothesis concept are identified through analysis of students' answers. The development in students' conceptions are

Aspects	Conceptual development	Activities	Reflections	Direct instruction
Explanation included	No evidence	Built into S2 and S3, not visible	No	some in S1
Basis and motive	Probably	Yes, especially S2	Not necessarily, very rare	Yes, S1 and S2, model
Testable by experiment	Clearly	Yes, S2 and S3	Possibly, but only for some	Yes, S1, S2, S4, feedback
Tool for scientific inquiry	Possibly	In S2, otherwise dependent on students	Yes! A main part of reflections	In S1 and S2, possibly in model, but not visible
Structural role	Clearly	Yes, repeatedly	Possibly, but only for some	Yes, repeatedly, in model

Table 6.2. The aspects of the hypothesis concept identified, my conclusions for conceptual development, and the degree of inclusion of each aspect in the different types of teaching and learning activities.

assessed for each of these aspects, and the summarised results are shown in the first two columns of Table 6.2.

RQ 2: There is a change in many students' general approaches to scientific inquiry. Students are more reflective, more aware of their approaches and not as easily satisfied with laboratory results. These conclusions are based on interviews, where three out of four students clearly communicate this change. One student expresses becoming more aware of the need to know where an inquiry activity will lead before starting to conduct experiments, as well as evaluating exactly what each experiment implies for questions posed. The reasoning is advanced, and captures much of the purpose of learning about hypotheses as a tool in the scientific inquiry process, but the student does not link this specifically to the use of hypotheses.

RQ 3: Some correlations for concept improvement and activity design are shown in Table 6.2. As can be seen from the table, some aspects are successfully included in the design, and correlated learning occur, while for other aspects, the sequence has less impact. In addition to what can be seen from the table, having some explicit part of the design that makes an aspect visible to the student is of great importance. There is also a difference in impact if an aspect is merely present in different types of activities, compared to when there is a planned connection between them. Feedback to both individual students and whole class is of great importance for visibility and connection between types of activities.

Regarding the more reflective approach to scientific inquiry in general, there is a specific guided reflection assignment on the fourth session of the sequence that had a large impact. This assignment is individually adapted and feedback-rich, linking to the students' previous practical performance. The assignment is successful in connecting the ideas presented in the direct instruction to the activities of scientific inquiry for many students, and the answers from that assignment correlate well with students' claims on major learning outcomes from the sequence. Overall, the results of this thesis suggest that students tend to reflect more on their chosen approach to scientific inquiry in general if repeatedly asked to motivate and account for their methods and choices.

RQ 4: This thesis shows that it is possible to teach explicitly in a meaningful manner *about* scientific inquiry and the concept of hypothesis. From the answers to RQ 1-3, it can be concluded that the sequence provides many examples of design for teaching about hypotheses that can successfully affect students' conceptions. The implications for teaching are summarised in the next section, 6.2, as concrete recommendations for teaching.

6.2 Recommendations for teaching

In this section, I present my recommendations for teaching explicitly about hypotheses. The recommendations are based on the results of this study and my interpretations of implications for teaching. This section is mainly intended for teachers interested in using ideas from my design, or further research interventions with very similar content (RQ 4).

The sequence developed constitutes a large part of my answer to RQ 4, and most of the recommendations in this section are related to it. See section 3.1 and appendix A and B for details on the sequence.

6.2.1 Recommendations for teaching about hypotheses

A first recommendation is that the key content which the students are meant to focus on in an educational sequence should be included often and in different types of teaching and learning activities. This is not enough, however, since it is easy for students to perceive different activities as separate. This calls for planning how the different activities link to one another, not just including seemingly connected content (Abd-El-Khalick and Lederman 2000). This can be done partly in the design of the activities, but feedback on both general and personal levels is almost invaluable in this respect. Both feedback and design of teaching and learning activities must strive to make the key concepts visible to the students (Hattie and Timperley 2007).

Table 6.2 can be used as a first guideline to some of the pedagogical choices in designing teaching about hypotheses. Firstly, all or some of the identified aspects of the hypothesis concept can be included in the design. In order to make them more visible, the chosen aspects should be explicitly presented to the students as central content. Secondly, the analysis of which aspects were successfully learnt in my implementation, and which were not, can be used for improving the design. According to my interpretation, my design works well for communicating non-linearity and that a hypothesis needs to be testable by experiments. That hypotheses include explanations is sufficiently present in activities of scientific inquiry, but will need to be made more visible by reflection or direct instruction. Hypotheses as a tool for scientific inquiry is sufficiently included in reflections, but needs to be expressed more clearly by the teacher, and visibly included in more activities of scientific inquiry. The basis and motive for hypotheses is visible in both activities and instruction, but needs to be included in explicit reflection assignments.

Furthermore, students may identify and focus on content differently from the teacher, and perhaps differently from each other (Bussey *et al.* 2013). Therefore, it is essential to pay attention to what is included and what is left out, and how the focus is steered to the central content. Compared to the planned and implemented sequence of this thesis, I would suggest that less, but more specific, content is used in order to facilitate for the students to focus on important parts. The model of scientific inquiry works fairly well, but communication about it should be more clearly linked to specific aspects of the hypothesis concept.

It is also important that the design of the laboratory sessions is in line with the theory about scientific inquiry that is presented. Whether this should be achieved through a restriction in the design, or by adaption of the theory to the school context, is a difficult trade-off. In the sequence presented in this thesis, I have made some adaptions to school context but tried to keep the core of the scientific hypothesis concept and its use.

The results as regards the transferability of the conceptual understanding are weak in this thesis. What can be said is, that in order to apply ideas of an iterative scientific process in practice, more time than 80 minutes is needed. Session 2 and 3 together are intended as a suggestion for how a scientific investigation might be conducted. The students are not able to replicate this in session 5. I suggest more time, or, if this is hard to realistically organise, simpler scientific content. In order to integrate these ideas of scientific inquiry in regular education, I suggest a smoother transition between teacher-controlled scientific inquiry and free investigation where the students takes full responsibility for every step of the design.

The basis for most guided reflection activities should be the actual performance of students on activities of scientific inquiry, preferably including feedback on that performance. A challenge arises, though, as regards how to include this link to practical performance and still keep the focus on such abstract content as conceptions of hypotheses. Two factors matter here. Firstly, make sure that the purpose of the assignment is understood by the students. Otherwise, it is easy for many students just to reflect on details in performance, or scientific content. Secondly, the questions should be specific enough, simply so that students know what they are supposed to do. In achieving these two points, teacher feedback on reflection is very valuable.

Therefore, it is wise to plan in such a way as to allow the teacher time to talk to all students during these activities.

In order to promote improvement of students' general approach to scientific inquiry, activities should be included that make students aware of their choices, and that make them question their own purposes for doing things in a certain way. One of the things expressed by students as a cause for learning was to fail using a certain approach, and then get an idea of what could remedy their error in the future. A climate where such failures are openly admitted, with pre-planned reflection activities and support to improve approaches, could be beneficial to learning.

6.3 Suggestions for further research

The observations and data from the study suggest that the impact was small when it came to use of ideas from session 1-4 in session 5. Except for a few examples, there seems to be little application of the ideas in the new context. The question of transferability of conceptual understanding needs to be further assessed.

One interesting observations during the work with classifications of students' definitions of the hypothesis concept is that many students consider only the school context. The laboratory session is seen as the arena for scientific inquiry, and thus the definition of hypothesis regards laboratory sessions only. Many students had such a focus in their definitions before and after the sequence, and traces of how scientific inquiry is performed in schools can be seen in more answers. These results could be an important factor in understanding how to work with students' conceptions. I suggest specific research to investigate this. Possible questions: To what extent do students consider the concept of hypothesis specifically in a school context? What are the reasons for this limitation of the students' view on context? What are the impacts on conceptual understanding if scientific inquiry is regarded strictly in a school context? How can teaching be designed to adress these problems?

Bibliography

Abd-El-Khalick, F. and Lederman, N. G. (2000). Improving science teachers' conceptions of the nature of science: A critical review of the literature.. *International Journal of Science Education*, **22**(7), 665–701.

Abrahams, I. and Millar, R (2008). Does practical work really work? - a study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education*, **30**(14), 1945–1969.

Bartholomew, H., Osborne, J. and Ratcliffe, M. (2004). Teaching students "ideas-about-science": Five dimensions of effective practice. *Science Education*.

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education*, **32**(3), 347–364.

Biggs, J. B. (2003). *Teaching for quality learning at university*. 2nd edn. Open University Press/Society for Research into Higher Education.

Bussey, T. J., Ogrill, M. and Crippen, K. J. (2013). Variation theory: A theory of learning and a useful framework for chemical education research. *Chemistry Education Research and Practice*, **14**(9), 9–22.

Chalmers, A. F. (1999). *What is this thing called science?*. 3rd edn. Open University Press.

Gyllenpalm, J. (2010). Teacher's language of inquiry - The conflation of methods of teaching and scientific inquiry in science education. PhD thesis. Stockholm University.

Hattie, J. and Timperley, H. (2007). The power of feedback. *Review of Educational Research*, **77**(1), 81–112.

Hodson, D. (1996). Laboratory work as scientific method - three decades of confusion and distortion. *Journal of curriculum studies*, **28**(5), 115–135.

Schwartz, R. S., Lederman, N. G., Norman, G. and Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, **88**(4), 610–645.

Skolverket Swedish National Agency for Education. (2014). *Skolverket* http://www.skolverket.se/polopoly_fs/1.194811!/Menu/article/- attachment/Physics.pdf (2014-05-22).

Säljö, R. (2010). Lärande och elevers utveckling. In: *Lärande Skola Bildning*. p 164. Natur & Kultur Stockholm.

Trumper, R. (2003). The physics laboratory – a historical overview and future perspectives. *Science & Education*, **12**, 645–670.

Appendix A

Sessions in detail

This appendix section includes detailed plans for all five sessions of the sequence.

Session 1 – Introduction

The goal of the first session is to describe to the students the purpose of my interventions and to give them an introduction to the concept of hypothesis and its role in scientific inquiry. Below follows something similar to a manuscript with the main ideas about what I should say to the students.

There are two different goals of physics education. Firstly, to give you specific knowledge about scientific content, and secondly to give tools and skills to approach science, giving the opportunity to look at the world in new ways. Leading questions for the second goal are: What do we know about the world? How do we know it? How can we find out more?

These two goals are interrelated, but I will focus on the latter. There are many different kinds of science and the approach is dependent on what area you are in. In physics it is common to use the words "observation, hypothesis, experiment and theory" as a framework to describe science. (Write these words on the board.) As you have previously discussed about models, this is just a model and cannot be said to be "the" description of science in physics. Before I say anything more I would like you to write down what you think the word hypothesis means. (Students answer the question "What is an hypothesis" on their computer or on paper.)

Now I will give you an example of how these words can be used. Take the issue of things falling to the ground. I observe that when nothing holds on to things, they tend to fall to the ground. I put up a hypothesis that all things will fall to the ground when I let go of them. I try experiments, different materials, different angles and throwing objects into the air. I seem to justify my hypothesis, with the addition that some things fall faster than others. I conclude and create a theory that all things move towards their natural place if nothing hinders them. Natural place would be the ground for solid objects. (This may sound ridiculous, but is actually the theory formulated by Aristotle that was in use in Europe from ancient

Greece, criticised by Galileo around 1600 and finally replaced by Newton in late 17:th century.)

This example shows that it is not always obvious how these words relate. When you looked at the falling objects you probably could "see" the gravitational force. So theory seems to influence our observations, can anyone give more examples of that? (In reserve: For example during your laboratory session with friction that I visited, you used Newton's laws and the concept of force to investigate friction.)

So the different parts influence each other. (Draw line from theory to observation) We will mainly focus on hypotheses, but since they all relate we will also look at how hypotheses relate to mainly observation and experiment.

So what is a hypothesis? You have written down your answers of which I see most at the screen here. One could say it is a guess about how something will behave under certain conditions, but this is missing something. (Relate to their answers appearing on the screen) I would like to add that the "guess" should be meaningful and tell us something of the object or phenomena we are looking at. If it's a scientific hypothesis it should be testable experimentally. My goal with these sessions is that we should become better at using hypotheses as a tool to investigate phenomena.

You have been using hypotheses before, for example during my visit to your laboratory session about friction. You looked at what happened, formulated some thought about how it works. Some of you looked in your collection of formulae for guidance, and everyone made some kind of experiment and tried to reach conclusions about your results. What I hope to do is give you the opportunity to be more conscious about the whole process, especially the part about formulating hypotheses.

So why use these "guesses" at all? Is it not sufficient to look at the world, make some experiments, and see how things work? It turns out that use of hypotheses can considerably improve the results of scientific inquiry compared to just observing and measuring whatever you come to think of. It gives direction to the investigation, but also makes interpretation easier.

Let me show you with an example. (I will lead the reasoning, but allow pauses to think. Relate everything done to the model on the board and let the students think of what parts my actions and reasoning correspond to.) How does a candle work? Let us see.

(Light the candle) We see that the wick is burning and the wax is melting, let that be our hypothesis. So how do we test it? A wick without wax burns quickly, that would fit into our hypothesis. How about a burnt out match? It does not burn anymore, but we try to dip it into melted wax and hold it into the fire again. It burns! It seems that the wax does burn, even when the match was burnt out. So our hypothesis was wrong. New one is that the wax burns, the wick is only there to start the process. If so, we should be able to burn a piece of wax, or molten wax on any object. It turns out we cannot, it only melts, so there is some function of the wick or the match that makes the continued burning possible.

We could now go on and investigate what different materials functions as wicks and how it works. You can actually see quite clearly if close enough how a burnt match absorbs the molten wax, but it is hard to demonstrate to everyone now. But look at what happens when molten droplets of wax fall at the wick, it shows that molten wax in the wick is what burns.

So we arrive at a hypothesis that the wax burns, but the wick and its ability to absorb molten wax is important for sustained burning. It is hard to come further with the theory, time and materials we have here. I will say a few more words about how it works, but let me make my points about hypotheses first, ok? So why did this show something about the usefulness of formulating and testing hypotheses?

It gave us the possibility to design meaningful experiments – without guesses, it would have been harder to think of the different possibilities. It gave us the possibility to interpret the results – if I would have just shown all these experiments to you without the progression in explanatory models. It would have been very hard to make any conclusions from them. How could we have known what the experiments proved or disproved? (if time some discussion about this)

(Explain more closely the function of the wick in a candle and how wax burns) This was not the main point of my demonstration. The idea was to show one way to use hypotheses. The reasoning could have been done in other ways, for example using more theory, to reach the conclusions quicker, but I choose to do it this way to make my point as clear as possible.

[Explanation of the practical structure for the rest of my sessions, and interviews, presented elswhere in this thesis.]

Session 2, formulation of hypotheses and discussing their use - 80 min

The second session is a laboratory session where the students investigate different representations of the concept of torque. Torque is not a part of their curriculum.

Intended learning outcomes for the session:

- The students can draw conclusions from their observations and previous knowledge to formulate hypotheses. (e)
- The students are familiar with comparing hypotheses. (b)

The session starts with the division of the students in groups of two (decided randomly in advance). There are four laboratory stations where students take turns to rotate. One further station is observing their classmates visiting the same station they just visited, and discuss the differences in approach and the consequences of this.

At the stations, the students try to formulate hypotheses about how the system works and try to find out whether they are correct or not. The students are handled a worksheet for documentation, see appendix B.

Station 1 Where a ruler with holes for loads is balanced around a pivot point.

Station 2 Where the students can build levers of different lengths and proportions.

Station 3 Where a construction allows a weight to be lifted with the help of a winch where weights or dynamometers can be applied at different distances from the pivot center.

Station 4 Where weights can be added at different specific positions on a freely rotating bicycle wheel.

Station X Where the students are to observe classmates at the station they just visited, to discuss the differences in approach and the consequences of this.

Each group gets five minutes at each station. They answer the questions at the worksheet at each station, this is both to make sure they formulate their thoughts and to provide data for analysis. We are now 35 minutes into the session. All groups are put together into larger groups of four. The assignment is to discuss one of their hypotheses and how they arrived at their conclusion. They write down if any group changes their hypothesis as a result of this discussion. (this was cancelled due to lack of time)

A new assignment is given to the larger groups. "Is there any connection between the stations? Can you find a common hypothesis that explains all or some of the stations?" The students can now go and revisit the stations and if they wish collect additional data.

With 25 minutes left of the session we gather for a short whole-class discussion. We discuss the more general hypothesis if any group has come up with something. Focus is on the evidence and reasoning for the hypothesis, rather than the exact formulation. The different hypotheses are compared, to show different levels of generalisation, and how seemingly different formulations can be similar. (This became a larger part than planned, and very successful!)

We then go on to create a summary of the function of hypotheses during this session. Questions to the students include: "What was the purpose of formulation hypotheses?", "What did we use them for?" and "Did it help us with anything?" I collect the answers on the board, with possible additions from me if necessary: "To be able to think focused on explanations to a phenomena." and "To be able to criticise each other's ideas." (This was smaller than planned, since the previous discussion took more time)

There are short discussions in the initial groups about how they worked with the assignments. The students answer the question on the worksheet, "If I were to redo the session, what would I have done differently in how I worked with formulation of hypotheses?"

As the last part of the session I link this to my model of observation, hypotheses, experiment and (possibly) theory. It became obvious that the previous knowledge had impact on what hypotheses you were able to formulate, for example those who knew levers from before, or those who made other assignments before the rotating wheel, had better possibilities. (Draw new lines)

Main message is to formulate hypotheses that are testable by experiment. This is not something we did today, but will be the main focus of next session. We will then practice to create experiments that really test the hypotheses. Finish session.

Session 3, testing hypotheses through experiment - 80 min

The third session is also a laboratory session, where the students now design and implement experiments to test hypotheses. The most general and useful hypothesis from session 2 is used as a starting point for this session, to be investigated and improved. The instruction to the students is the best summary for this session, see appendix B.

Intended learning outcomes of the session:

- The students can draw conclusions from data to refine hypotheses. (g)
- The students have improved their ability to implement experiments to test hypotheses. (f)
- The students can use observations during a laboratory session to change their investigation. (f)
- The students have a better understanding of the importance of the wording of the hypothesis for how productive it is and how it can be tested. (b)

Note that the ability to creatively design experiments is not necessarily exercised here, since the students mainly use the same materials and probably the same experiments as in the previous session.

Session 4, reflect on own methods of scientific inquiry - 30 min

The aim of the fourth session is to use student discussions to focus the students on learning from their experience from session 3. Therefore, the intended learning outcomes for session 4 are essentially the same as for session 3, but cognitive instead of experience-based. In conversation with the class, different examples of good use of hypotheses and experiments are mentioned. I point out important aspects of learning in relation to the purpose of session 3. This is based on the reports from the students. The model of scientific inquiry is drawn again, with the addition of a research question as a guideline for investigations. Then the reports, with written feedback, are handed back to the students. The feedback on the reports is based on the assessment criteria given in the instructions. A grading, only focused on hypothesis use, is also included. On each report there is one written question for the students to discuss about their performance and strategies. This question in unique for every group and focuses on some aspect of scientific inquiry that is judged problematic or interesting in their report.

Questions to students can be more specific variants of the following: "How did you choose what experiments to make?", "Did you start with the first thing that you came to think of?", "Did you know before you started what questions the experiment was supposed to answer?" "How did the experiment relate to the hypothesis?" or, again, "What would you do differently if you were to do the laboratory session again?"

Session 5, using hypothesis skills in a known context - 80 min

In this last laboratory session the students should try to implement what they have learnt from the previous sessions in a new context. Intended learning outcomes, apart from repetition, are:

- Students can formulate hypotheses so that they become testable by experiment (e)
- Students know how to design experiments that test hypotheses. (f)

Main structure of the session can be seen in the instruction given to the students, see appendix B.

Feedback is given in written form on the laboratory reports. When handing them back to the students I also hold the last conversation with them about my interventions. Here I give feedback on their performance based on the reports. I draw my model again and add some more arrows but mention that the picture is not completed yet. We have not been talking at all about what affects theory for example. The main message is to once again emphasise the important role that hypotheses can have in scientific inquiry, but that the use is not a recipe to follow that will guarantee any results. The use of hypotheses is not the same in every situation, and there is not one scientific method, as you can see from the model picture. (This part never came to be in my implementation, since the grading of the reports as a part of the students regular education took a long time, and I judged it problematic to give such feedback and instruction close to interviews and the second time the students should answer "what is a hypothesis?". But this was a desicion strictly based on relability of students answer, from the perspective of research. From a pedagogical point of view, such feedback should definitely be included.)

Appendix B

Documents for students

These documents are intended for teachers in upper secondary schools, who might want to use parts of my sequence in their education. This section includes all the hand-outs for students, for session 2, 3 and 5 respectively. Both English and Swedish versions are included.

Worksheet session 2

For each station you are to formulate hypotheses for how they work, and explain why you think so based on your observations.

Station 1
When is the ruler in balance?

What have you seen that makes it probable that it is as you state above?

Station 2
What decides how easily something is lifted by a lever?

What have you seen that makes it probable that it is as you state above?

Station 3
What decides how easily something is lifted with the winch?

What have you seen that makes it probable that it is as you state above?

Station 4
What is needed for the wheel to be at rest and what decides which way it turns?

What have you seen that makes it probable that it is as you state above?

Station 5
Observe the other group, what is the difference in approach to the assignment compared to when you did it?

What pros and cons can you identify with their way of approaching the problem?

In new larger groups
Choose a station that you found interesting. Discuss your hypotheses and what made you arrive at that conclusion. If you do changes to your hypothesis after group discussion, write it here, with an explanation why it is better.

New assignment
Is there any connection between the stations? Can you find a common hypothesis that explains all or some of the stations? You can revisit stations to help the search for a new general hypothesis. Write down any conclusions.

Reflection
If you were to do the session again, would you have had a different approach to how you tried to formulate hypotheses?

Instruction session 3

Based on the previous session, I have formulated a hypothesis. Your assignment is to try the hypothesis and decide if it seems correct or if there is anything to change or specify. The goal of the session is to test hypotheses by experiment. How do we know if something is true? Why do we believe some things to be true? How can we get more certain?

You are to write a report where the following parts should be included:
Experiment - What experiments were carried out? Pictures could help to clarify here.
Result - A list of the measurements and the results from the experiments.
Consequences for the hypothesis - Did the results confirm the hypothesis, disprove it, or is there any way to improve it based on your result?

You are allowed to describe experiment, results, and changes in hypothesis alternately, as long as the separation between them is clear. (Note that this is an exception from your standard laboratory reports) The important content is your work and thought process.

Assessment of the report is done due to following criteria:
To what extent the experiments test the hypotheses.
How valid conclusions you are able to present based on the results of the experiments.
How well you are able to formulate a new hypothesis if your results call for a change.
There is no assessment on how similar your hypotheses are to the current theory.
Focus is on the work you do and the conclusions you draw from your own experiments and observations.

Instruction session 5

Here, you are to use what we have learnt during the previous sessions about hypotheses to be as effective as you can when investigating something that you need to find out. The physics content of this laboratory session is included in the curriculum of Fysik 1. Theory is presented after the laboratory report is written. The assignment is to investigate forces on solid objects in water. We know that objects are lighter in water and that some things float while other sinks. The phrasing of the question already contains some information and theory to guide you:
"The water acts with an upward (buoyant) force on solid objects in water, what decides the amplitude of this force?"

A proposal for approaching the question using the previous experiences about hypotheses is given below. You may choose another approach if you find it appropriate.

Formulating hypothesis: You have different objects to try, and probably experience of several more. Formulate a hypothesis that tries to answer the given question. What quantities determine the buoyant force?

Hypothesis testing: You should have one or more hypotheses about what decides the amplitude of the buoyant force on objects in water. Design and implement experiments to test these hypotheses.

Evaluation: Were your hypotheses correct? What in your data implies that they are either true or false?

Refine hypothesis: This is basically to return to step one. Is anything disproven? Does anything need correction or refinement that you can see from experimental data? What is your current hypothesis? Here you can go back to hypothesis testing if necessary, to collect more data and make your hypothesis more probable.

You are to write a full laboratory report on this session, according to your usual guidelines. You should include the hypotheses you formulate and how the experiments relate to them.

Assessment on hypotheses is mainly based on the following two criteria:
-To what extent you formulate your hypotheses so that they are testable by experiment, and that the experiments actually are valid tests of your hypotheses.

But the quality as a whole will also be assessed. Including correct language, use of theory, logical arguments, clearly presented results and so on according to your guidelines on how to write a laboratory report.

It is possible that you are familiar with possible answers to the question. If that is the case this session becomes a somewhat more difficult but more focused exercise in decide what conclusions you can draw from experimental results. The key challenge then is to differentiate between your theoretical knowledge and what you have shown with experiments.

Arbetsblad till lektion om hypotesuppställning

Ni ska för varje station ställa upp hypoteser för hur de fungerar, och förklara varför ni tror det utifrån era observationer.

Station 1
När balanserar linjalen?

Vad har ni sett som pekar på att det är så som ni påstår här ovanför?

Station 2
Vad avgör hur lätt det går att lyfta något med en hävarm?

Vad har ni sett som pekar på att det är så som ni påstår här ovanför?

Station 3
Vad avgör hur lätt det går att lyfta en tyngd med hjälp av vinchen?

Vad har ni sett som pekar på att det är så som ni påstår här ovanför?

Station 4
Vad krävs för att uppställningen ska hänga stilla och vad styr vilket håll den rör sig åt?

Vad har ni sett som pekar på att det är så som ni påstår här ovanför?

Station X
Titta på hur en annan grupp jobbar med en station, vad finns det för skillnader?

Vilka för- och nackdelar har deras sätt att jobba jämfört med ert?

I nya sammanslagna grupper
Välj en station som ni tyckte var intressant, diskutera era hypoteser med varandra och hur ni kom fram till den. Om ni gör ändringar i er hypotes efter gruppdiskussion, skriv ner den nya här, med motivering till varför den är bättre.

Ny uppgift
Finns det något samband mellan de olika stationerna? Kan ni hitta en gemensam hypotes som förklarar flera av stationerna på en gång? Vilka samband har ni sett?

Nu kan ni gå runt i de grupper om fyra som skapats och återbesöka stationerna när man söker och diskuterar en större hypotes. Skriv ner. (Helt ok att också förbättra de hypoteser på varje station som ni har ställt upp, om ni kommer på något).

Reflektion
Om ni hade gjort om laborationen, hade ni haft någon annan metod för hur ni ställde upp hypoteser?

Hypotestestning

Utifrån förra laborationen har jag formulerat en hypotes. Er uppgift är att testa denna genom experiment som ni själva utformar. Ni ska se om hypotesen verkar stämma, om den är felaktig eller kan skrivas på något bättre, mer exakt sätt.

Målet med laborationen är att öva på att testa hypoteser och värdera hur korrekta de är. Hur vet vi om något är sant? Varför tror vi att något är sant? Hur kan vi bli säkrare? En viktig metod är att försöka komma på så många olika sätt att testa hypotesen på som möjligt. Det kan därför vara värdefullt att lägga lite tid på att förstå exakt vad hypotesen säger.

Ni ska skriva en rapport där följande delar finns med:
Experiment - Vilka experiment utfördes? Gärna med bilder så att det blir lätt att förstå.
Resultat - Vad gav mätningarna i experimenten?
Konsekvenser för hypotesen - Bekräftade resultatet hypotesen? Motbevisades (falsifierades) den? Kan ni förbättra den utifrån ert resultat?

Det är helt ok att beskriva experiment, resultat, ändrad hypotes och nya experiment för den nya hypotesen utifrån det om vartannat, bara det är tydligt vad som är vad. (OBS att detta är ett undantag jämfört med vanliga labrapporter!) Det är er arbetsgång och tankegång som är viktig.

Bedömning av rapport sker på följande kriterier:
Hur väl experimenten testar hypotesen.
Hur väl ni drar slutsatser om hypotesen utifrån experimentens resultat (förstärktes, ändrades, eller motbevisades).
Om aktuellt: Hur väl ni formulerar om hypotesen utifrån experimentens resultat.

Det sker ingen bedömning på hur nära den nuvarande teorin ni kommer i era hypoteser. Fokus är på hur ni utför och drar slutsatser från era egna experiment och observationer.

Utgångshypotes: För att ett föremål med fast vridpunkt inte ska vrida sig måste kraften nedåt gånger sträckan på ena sidan vridpunkten vara lika stor som kraften nedåt gånger sträckan på andra sidan. Vridpunkt är den punkt som ligger stilla när föremålet vrider sig, sträckan är avståndet från kraftens angreppspunkt till vridpunkten.

Laboration om lyftkraft i vatten

Här ska ni använda det vi gjort på de tidigare två laborationerna om hypoteser för att så effektivt som möjligt undersöka något ni verkligen vill ha reda på. Fysiken i denna laboration ingår i kursplanen för Fysik 1, genomgång av teorin blir efter labrapportens inlämning.

Vi tittar på hur fasta föremål i vatten beter sig. Vi vet att saker blir lättare i vatten, och att några saker flyter och andra inte. Nu ska vi undersöka precis hur det hänger ihop. Detta gör vi med en fråga som redan innehåller en del tolkning: Vattnet utövar tydligen en lyftkraft på föremål i vatten, vad avgör hur stor den blir?

Förslag på arbetsgång för att utnyttja det vi gjort om hypotestestning ser ni nedan, men det är tillåtet att välja en annan arbetsgång om ni har en bättre idé.

Hypotesuppställning: Ni har olika föremål att testa med, och säkert erfarenhet av fler. Gör så många iakttagelser som ni behöver för att ställa upp en hypotes som försöker svara på frågan ovan. Vilka storheter påverkar lyftkraften?

Hypotestestning: Ni bör ha samlat på er en eller flera hypoteser om vad som avgör hur stor lyftkraft vattnet har på föremål. Ställ upp experiment för att testa dessa hypoteser.

Utvärdering: Stämde era hypoteser? Vad i era data talar för eller emot?

Förfina hypoteserna: Nu när ni gjort experiment, är det någon hypotes där ni kan göra en bättre gissning eller en mer precis beskrivning av vad som påverkar lyftkraft? Här kan ni möjligen gå tillbaka till hypotestestningen igen för att samla mer data.

Laborationsrapport Ni ska skriva en fullständig laborationsrapport enligt er vanliga mall.

Rapporten bedöms i sin helhet, men vad gäller hypoteser är det bra att fokusera på följande: -Hur väl ni formulerar hypoteser så att de blir testbara -Hur väl era experiment verkligen testar era hypoteser

Det kan hända att ni känner till möjliga svar på frågan sedan tidigare. I så fall blir det på ett sätt en svårare men tydligare övning i att avgöra vad ni kan säga utifrån experimentresultat. Då gäller det att verkligen avgöra vad ni kan säga utifrån era undersökningar och vad som är teoretisk kunskap som ni inte har visat med experiment.

Appendix C

Interview protocol

This appendix chapter includes a translation of the protocol used during interviews. It is slightly adjusted for each student, depending on their written answers for examples. The questions below were used as general guidelines and frame questions. Almost every question were followed up by questions asking students to give examples, elaborate or specify more.

Introduction: The interview is a part of my research. It is not a part of the education, and nothing said here will be mentioned to your teacher or in any other way affect the physics course. Sometimes it will be hard to answer directly, so if you need time to think before answering, take that time. It is normal with silent passages. I will record the interview. It is only I who will listen, and if I use quotes they will be anonymous, OK?

So, first I would like you to tell me about the sessions I've held. Can you describe the sequence of sessions briefly and what you think they were about?

Session two was the laboratory session which included different stations where you went round to each. Can you describe what you did during this session?

What do you think the purpose was with this session?

During the session, there was an assignment about observing another group by one station.
"Observe how another group work at the station, what are the differences?"
"Which advantages and disadvantages are there compared to your approach?"
What did you think of this assignment, did it give something?

At the end of the session, you got to answer this question:
"If I were to redo the session, what would I have done differently in how I worked with formulation of hypotheses?"
What are your thoughts on this type of question at the end of a session?

During session three you were to freely investigate the hypothesis we arrived to at the end of session two. Can you describe what you did during that session? What do you think is the purpose with that session?

Same question for session five. What did you do, and what was the purpose?

(Show the model) Several times during the sessions, I showed this model. Can you describe to me what it says about scientific investigations? Can you remember if you used it during any other parts of the sessions? Do you think it had an influence on how you did or thought about something?

Is it anything special that you learnt during these session?

What made you think of that? -or what made you learn that?

In which way is it relevant?

Is there anything else you think you will use from these sessions in the future?

The fourth session was when I handed back the laboratory reports, and you wrote reflections on my questions. (show their question and answer) You wrote like this, do you see anything in your answer that's important? Can you elaborate, why is it important? Have you used this at any later opportunity?

During the last session, did you use any ideas or experiences from previous session?

Can you give an example of an hypothesis?

What makes this a hypothesis?

Is it a good hypothesis? What makes it good/bad? What makes a hypothesis good/bad in general?

What are hypotheses used for?

(show student's own initial definition) You answered this when first asked what a hypothesis is. What do you think of this answer now? Would you like to add or change something?

Someone else answered in this manner (show example from another student), what do you think of this answer?

During session two and three we used hypotheses in many different ways, can you describe how?/like you described before. How do you think that correlates with your description of what a hypothesis is and how it is used?

You can regard these two sessions as one long investigation of the same phenomena. If you compare to how you used hypotheses then to how you did on session five, what are the differences and similarities? Did your use during session 5 correspond to how you think it should be used?

Any other impression you would like to share from the sessions I've had with you?