Learning Physics Through Communication During Laboratory Work
An Empirical Study at Upper Secondary School

Jan Andersson
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DOCTORAL THESIS

Karlstad University Studies  |  2017:20

urn:nbn:se:kau:diva-48454

ISSN 1403-8099

ISBN 978-91-7063-781-0 (print)

ISBN 978-91-7063-782-7 (pdf)

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Distribution:
Karlstad University
Faculty of Health, Science and Technology
Department of Engineering and Physics
SE-651 88 Karlstad, Sweden
+46 54 700 10 00

Print: Universitetstryckeriet, Karlstad 2017
Abstract

Laboratory work as a teaching and learning method is given prominence in the Swedish physics curriculum for upper secondary school. It is emphasised that students should be given opportunities to develop the ability to search for answers to questions, plan, conduct, interpret and present results. Moreover, students should also be encouraged to use their physics knowledge to communicate, argument and present conclusions. This thesis is based on the belief that physics laboratory work creates a special discourse, where the student becomes the actor and the teacher becomes the organiser and observer. Such an environment enables students to naturally engage in physics discussions using their own terms. The aim is to explore students’ laboratory work at upper secondary school in-depth, with respect to its design and influence on students’ communication. Through analysis of students’ communication, the purpose is to better understand the physics laboratory work’s possibilities as a teaching and learning method. This will contribute to ongoing debate about the effectiveness of laboratory work. The results show that laboratory work consists of similar activities but differs in amount of time allocated to the different activities. Different types of talk are used for different purposes. An analytical framework has been created to enable deeper investigations of how and what students are talking about at both a linguistic and cognitive level. Moreover, the analysis shows the importance of students acquiring knowledge about physics and understanding the value of using an investigative approach as well as acquiring core content physics knowledge.
Acknowledgements

The process of writing this thesis has been both exciting and challenging. This work would never have been accomplished without the help and support from all the people that have followed me on this journey. I will therefore take the opportunity to thank all of you who made this possible.

First of all, I would like to thank my supervisor Margareta Enghag, who, with her passion for research and ability to see what is important, has inspired me and kept me on track. It has been a true privilege to have you as my supervisor and research colleague. Without you, none of this would have been possible.

Gunnar Jonsson, my co-supervisor, thank you so much. I have really appreciated and felt your support during this project. Your constructive comments on my manuscripts and willingness to discuss my work with me have meant a lot.

Kjell Magnusson, my co-supervisor, for your great support and wise advice. It has been a comfort to always know that you would help me whenever necessary.

Peter Gustafsson, opponent on my licentiate seminar, thank you for the valuable comments on my research.

I would like to thank Jesper Haglund, for an important contribution at my 90% seminar. Your suggestions have significantly improved this thesis.

Thanks to everyone in SMEER, Science, Mathematics and Engineering Education Research group, who have read, discussed and commented on my manuscripts. A special thanks to Birgitta Mc Ewen, for your support and carefully reading and written comments to my manuscripts, presented at the seminars.

Thanks to Torodd Lunde, for your thoughts and comments on my work. I have really appreciated our discussions.

Thanks to all my colleagues at the physics institution. Your support and concerns have been important to me, and I look forward to continuing my work together with you.
Thanks to the teachers and amazing students that took part in this research. You opened the door to your classrooms and let me take part in your lessons. Without your help and courtesy, this could not have happened. Thank you for your fantastic engagement and for sharing your thoughts with me.

Thanks to all my colleagues at Karlbergsgymnasiet in Åmål. A very special thanks to Tommy Gustavsson, Maria Bijlenga, Susanne Jansson, Gustaf Kallenius, Hans Henriksson, Lennart Wikström, who, with your great enthusiasm, have inspired and made me appreciate the teaching profession. An extra warm thanks to Lars Sundberg who unfortunately passed away, far too early. A great colleague and friend who advised me to apply for the position.

Thanks to my dear mother and father, Ulla-Britt and Karl-Erik, for your unlimited concern, sympathy and willingness to help and support my family and me. You both are truly wonderful.

And finally, thanks to my own fantastic family, to Camilla, Emma and Elsa. Watch out everyone! The famous chatter bubble is about to burst! I’m back and I cannot wait until I can once again spend more time together with you. Love you!

Âmål Valborg 2017
Jan Andersson
List of papers

Paper I

The Effectiveness of Laboratory Work in Physics: A Case Study at Upper Secondary School in Sweden.


Paper II

Different Styles of Laboratory Work – Different Types of Communication: Students’ talk during laboratory work in upper secondary school physics.

Jan Andersson, Margareta Enghag
(Submitted)

Paper III

The relation between students’ communicative moves during laboratory work in physics and outcomes of their actions


Paper IV

Open Inquiry-Based Learning in Physics – Students’ Communicative Moves Under Scrutiny

Jan Andersson, Margareta Enghag
(Submitted)
Authors’ contributions

Authors’ contributions to Paper I

The overall work on this paper was done in collaboration by the first author Jan Andersson and the second author Margareta Enghag. Both authors read and approved the paper before submission.

The first author’s contribution to Paper I

• The overall plan and idea of the project
• Collecting data and transcribing data
• Analysing the data
• Writing text for all parts of the paper

The second author’s contribution to the Paper I

• Mentoring the idea, the design and the writing process
• Collecting data

Authors’ contribution to Paper II

The overall work on this paper was done in collaboration by the first author Jan Andersson and the second author Margareta Enghag. Both authors read and approved the paper before submission.

The first author’s contribution to Paper II

• The overall plan and design of the project
• Collecting data and transcribing data
• Analytical framework
• Analysing the data
• Writing for all parts of the paper
• Executing the submission process

The second author’s contribution to paper II

• Mentoring the idea, the design and the writing process
• Validating the analysis and results
Authors’ contribution to Paper III

The overall work on this paper was done in collaboration by the first author Jan Andersson and the second author Margareta Enghag. Both authors read and approved the paper before submission.

The first author’s contribution to Paper III

• The overall plan and design of the project
• Collecting data and transcribing data
• Analysing the data
• Writing for all parts of the paper
• Executing the submission process and correspondence with the publishers

The second author’s contribution to paper III

• Mentoring the idea, the design and the writing process
• Discussing the analytical framework
• Validating the analysis and results
• Writing parts of the introduction

Authors’ contribution to Paper IV

The overall work on this paper was done in collaboration by the first author Jan Andersson and the second author Margareta Enghag. Both authors read and approved the paper before submission.

The first author’s contribution to Paper IV

• The overall plan and design of the project
• Collecting data and transcribing data
• Analysing the data
• Writing for all parts of the paper
• Executing the submission process

The second author’s contribution to paper IV

• Mentoring the idea, the design and the writing process
• Validating the analysis and results
• Proofreading of the final manuscript
Table of Contents

Abstract .................................................................................................................3
Acknowledgements ..............................................................................................4
List of papers ........................................................................................................7
  Paper I ...............................................................................................................7
  Paper II .............................................................................................................7
  Paper III ...........................................................................................................7
  Paper IV ..........................................................................................................7
Authors’ contributions ..........................................................................................8
Preface ................................................................................................................13
The thesis aim, purpose and research question .................................................14
  Research questions from each paper ..............................................................14
  Contribution ....................................................................................................15
The link between the papers ..............................................................................16
Introduction ........................................................................................................21
  What is laboratory work? ................................................................................21
  The development of laboratory work as a teaching and learning method ....23
  The aims and goals of practical work .............................................................24
  Different forms of laboratory work ................................................................26
  The importance of communication in physics education .............................30
  Students’ communication in small groups .....................................................32
  Learning through working in small groups ...................................................35
  Language as a social mode of thinking ........................................................37
  Research about kinematics in physics ............................................................37
Theoretical Perspective ......................................................................................39
  Ontology and epistemology positioning .........................................................39
  Methodology considerations ........................................................................42
Method ............................................................................................................44
  Data collections .............................................................................................45
  Analysis methods ..........................................................................................46
Reliability, Validity and Generalisability ..........................................................52
Summary of the thesis’ papers ............................................................................55
  Paper I .............................................................................................................55
  Paper II ..........................................................................................................58
  Paper III ..........................................................................................................61
  Paper IV ..........................................................................................................64
Discussion ..........................................................................................................66
  Effectiveness of laboratory work .................................................................66
  Students’ communication ..............................................................................67
  The physics curriculum ..................................................................................69
  Further research .............................................................................................71
References ..........................................................................................................72
Preface

The physics subject at upper secondary school in Sweden is only available for students attending technology- or science programmes. The first course, Physics 1, is mandatory for both programmes. Depending on the choice of specialisation, students can study an additional physics course, Physics 2. At some schools, students are also given the opportunity to study an advanced course, Physics 3. In the Swedish physics curriculum (Swedish National School Agency, 2011), it is expressed that students should be given opportunities to develop their ability to search for answers, plan, implement, analyse and present experiments, make observations as well as handle materiel and equipment. Students should also be given opportunities to use their knowledge in physics to communicate and use information (Swedish National School Agency, 2011). However, how these aims should be attained is not mentioned in the physics curricula. The physics teacher is responsible for designing the physics education to accommodate these expressed aims. This relatively sharp emphasis on both the actual laboratory work and that students linguistically are expected to take part in the physics discourse, makes research in this area extra important.

With my background as a teacher in mathematics and physics at upper secondary school, I have had the privilege of working with several experienced physics teachers. Their knowledge, enthusiasm, curiosity and positive attitudes contributed to my own interest in physics and questions related to physics education. Many of the discussions with my colleagues now and at that time revolved around the didactical question of how physics content should be presented to students. I have always appreciated using laboratory work as a teaching method and when I was given the opportunity to choose my research field within physics education it felt natural to deeper investigate the laboratory work’s affordances.

I believe that laboratory work in physics has especially good potential to offer students opportunities to develop their understanding in physics as well as about physics, through the use of talk. The laboratory work creates a unique discourse, where students become the actors and the teacher takes on the role as organiser and observer. I believe students can naturally speak the physics language using their own terms when given such an environment.
The thesis aim, purpose and research question

It is from the above-mentioned thoughts and ideas the work in this thesis departs, where the aim is to explore more deeply students’ laboratory work at upper secondary school with respect to its design and influence on students’ communication. The purpose is to better understand the physics laboratory work’s possibilities as a teaching and learning method through the analysis of students’ communication.

The overarching research question in this thesis is:

- How can physics laboratory work at upper secondary school be structured and implemented to enhance students’ learning in and about physics?

The overarching research question stems from the research questions in the four different papers presented below. I will use the results from the four articles to further explain my own thoughts and ideas concerning this overarching question. These reflections will be elaborated in the thesis’ concluding discussion.

Research questions from each paper

How can efficiency of laboratory work be seen as:

- A comparison between teacher’s goal of intended learning outcomes and students’ learning outcomes expressed in interviews and written reports?

- A comparison of the activity that students are supposed to do and what they actually do?

(Paper I)

- How does the style of the laboratory work influence the talk-type between students?

- What activities are generated by the laboratory work and how do the activities influence the talk-types between students?

(Paper II)
• What student interactions are communicated during laboratory work in physics when different talk-types are in use?

• What is the content being communicated during laboratory work in physics when different talk-types are in use?

(Paper III)

• What communicative moves are relevant when students are given the opportunity to plan their own inquiry in the laboratory work in physics?

(Paper IV)

Contribution

The results show that laboratory work consists of similar activities but differs in amount of time allocated to the different activities. Different types of talk are used for different purposes. An analytical framework has been created to enable deeper investigations of how and what students are talking about at both a linguistic and cognitive level. Moreover, the analysis shows the importance of students acquiring knowledge about physics and understanding the value of using an investigative approach as well as acquiring core content physics knowledge.
The link between the papers

The papers are listed in the same order in which they were produced. The progression of the data collection and links to the papers are described below and graphically illustrated in Figure 1.

Initially, the aim of the project was to follow a physics teacher and a class of students over a period of three years and together with the teacher implement three laboratory lessons each semester, with different degrees of freedom. The purpose with such a longitudinal study was to investigate in-depth how different forms of laboratory work contributed to students’ and the teacher’s learning. A physics teacher with a class of 20 students at a Swedish upper secondary school accepted to take part in the project, which was planned to proceed from Spring 2012 to Spring 2015. The teacher divided the students into five comparable heterogeneous groups that were envisioned to stay intact throughout the project.

Unfortunately, the planned continuity of the project, with repeated data collections, was interrupted after one semester as the teacher accepted an offer for another position at a different school. The succeeding teacher willingly agreed to continue with the project over the next semester. A third teacher at the same school showed great interest in the project, whereupon I was given the opportunity to start following this teacher and a new class of students. The initial intention, to follow one teacher and one class of students, over a period of three years, was thus gradually revised, as three teachers and two classes of students ended up contributing to the project. The four papers presented in this thesis build upon three different data collections, one for each teacher (see Figure 1). Paper I stems from data collection 1, with the first teacher. Paper IV builds upon data collection 2, gathered with the same class of students as paper I but with another teacher. Papers II and III build upon data collection 3 with a third teacher and different students compared to those participating in data collections 1 and 2.
The links between these four papers are graphically illustrated in Figure 2. The work was carried out with the physics subject at upper secondary school level as a backdrop, and further confined to the context of laboratory work and students’ communication. The first paper originates from the first data collection where the teacher was asked to design a closed laboratory work activity. The purpose of the paper was to explore the effectiveness of the activity, by using an analytical instrument designed to examine the teacher’s intentions with the activity, in relation to the students’ actions and learning outcomes. The analysis emphasised the complexity of the effectiveness concept. The analytical framework used did not take the laboratory task’s level of severity into consideration. The analytical model did though incorporate students’ communication in the sense that students’ use of concepts and ideas were compared to the teacher’s declared intentions. The actual efficiency of students’ communication in relation to the design of the activity was however not embedded in the analytical process.

During the data collections that followed, I started to develop an interest in the way in which students used communication as a tool for understanding physics. The students’ use of language and ways of communicating physics between them seemed to change character in different settings. This phenomena became apparent to me during data collection 3, where students in groups of three to four were asked to perform activities at four different workstations, during a laboratory lesson with the theme of uniformly accelerated motion. The design of the workstations differed not only in the actual physics content but also in the way students were expected to approach the given tasks. During the video
recordings of students’ conversations, I noticed variations in how students communicated with each other, at the different workstations. Some of the workstations seemed to foster more qualitative talk between students than others. The concept of effectiveness addressed in paper I evolved in paper II to also comprehend the efficiency of the students’ communication. The influence and impact of students’ communication in regard to the design of the physics laboratory work became focus of scrutiny. A quantitative descriptive analytical approach was undertaken to shed light on the correlation between the laboratory style and students’ communication.

At this time I realised that my initial research interest in different forms of laboratory work started to lean more towards students’ use of communication in the context of laboratory work. During the many hours of watching and observing the video recordings of students’ laboratory work, it became clear to me how important the role of communication actually is for students to make connections between their observations and create new understanding and knowledge. As a consequence of the quantitative analysis of paper II, a need for a deeper and a more fine-grained qualitative approach arose, which could be used to better follow a group and individual students’ progression. An analytical tool was needed to better understand, not only how students talked but also the content in which students talked about the physics laboratory work, at both a linguistic and cognitive level. The outcome of these thoughts and ideas

Figure 2. The link between the four papers covered in the thesis. An explanation of the arrows is provided in the text discussing the links.
eventually resulted in the theoretical analytical framework presented in paper III. The data collection used in paper II was revisited in paper III but with a new qualitative analytical approach. Students’ conversations where transcribed verbatim, and a thematic analysis was performed with four guiding questions. The aim was to find speech patterns in relation to how students spoke and interacted and what physics content and purposes they expressed during their conversations. The framework accentuates the relation between students’ communicative moves and outcomes of their action. This framework contributes to the ongoing debate about the effectiveness of laboratory work, in the sense that it offers researchers and science teachers a systematic way to afterwards analyse students’ conversations during the laboratory work. Through such an analytical approach, the concept of effectiveness is broadened to also comprehend the efficiency of students’ talk and furthermore enables analysis of students’ progression. After the work with paper III, my intention was to continue exploring students’ communication in the context of the physics laboratory work. Based on the analysis presented in paper II, it became evident that some laboratory activities, such as planning, processing data and analysis of results generated more cognitive demanding talks than activities such as preparing equipment and collecting data. The result in paper II also indicated that laboratory works of a more open character consists, to a higher degree, of activities that generate more cognitive demanding conversations. Traditionally, laboratory work at upper secondary school is often well structured, where students are given thorough instructions concerning what to do and sometimes also how to do it. Physics laboratory work of a more open character generally does not occur so often, even if promoted in the physics syllabus. With this in mind, I wanted to use students’ communication as a tool to further explore the grounds on which students made their decisions when given the opportunity to plan, implement and analyse their investigation. These plans were then realised in paper IV, where I chose to use the extensive data collection 2. Paper IV builds upon an intervention, where the teacher was asked to let the students plan and design an investigation based on their own ideas and questions. The analysis in the paper focused on students’ planning phase, where the individual student’s views and ideas were to be addressed, negotiated and transformed to something that united the group and in the end was possible to accomplish, within the boundaries of the school’s available physics equipment. The analytical framework from paper III was here used to structure a discourse analysis of students’ communication. The analysis showed that students had diverse opinions about what constitutes an investigation and how to use it to find answers to posed questions.
The initial plan to follow one teacher and one class of students for a period of three years of physics studies was revised at an early stage. As a consequence, the design of this PhD project became more flexible, and my research interest expanded to include students’ communication in the context of laboratory work. I think that this modification has contributed to a more dynamic and interesting research, where students’ communication has been both elaborated in the special discourse of laboratory work and where students’ communication has been used to examine consequences of using physics laboratory work as a teaching and learning method.
Introduction

What is laboratory work?

What do we actually mean when we talk about laboratory work? The term laboratory work is widely used and is most likely associated with a school context in many different ways. For some, the thoughts go directly to small group activities in a science subject, where students conduct investigations by using special equipment and materiel. Others might think of white coats and safety goggles that are used when handling hazardous chemicals. Some perhaps refer to biology excursions and field trips. Irrespective of these different associations, the common denominator of laboratory work is that students have been given a demarcated assignment to work with during a specific period of time. The character of the task outlines the frames for the laboratory work. The task can be well defined to include specific questions to be investigated and answered, or frames a specific theoretical area that the work focuses on. During these occasions, students often work practically in any form, which means that students are not just passive receivers of information. The laboratory work often includes handling of equipment and instruments in different forms. The use of equipment enables students to perform observations and collect information but can also be implemented to acquaint students with it and used to foster procedural skills.

The laboratory work in science education is usually accomplished in small groups, where students work together in groups of two to four. The use of laboratory work changes both the work- and learning environment, compared to when the teacher gives traditional theory lectures to a whole class. During the laboratory work, the teacher usually takes on a more passive role and acts more like a mentor. Focus shifts from the teacher to the students, who are expected to take charge of the moment. The laboratory work here creates a discourse of its own that gives students an opportunity to communicate more easily using their own terms.

The terms laboratory work, practical work and experiment are often used synonymously. Hult (2000) defines experiment as an activity where students are offered opportunities to try and verify a thought or a theory. The term laboratory work can, according to Hult (2000), be equalised with the term experiment but can also be used to illustrate something that can be a theory as well as a procedure. The definition of practical work becomes an expansion of the terms experiment and laboratory work, where the student is not just a
passive auditor or observer. Hodson (1988) sees these terms as subsets of each other (see Figure 3). The experiment is a subset of the laboratory work that is a subset of the practical work, which can be considered as one of many different teaching and learning methods. Practical work does not necessarily imply that students are doing laboratory work, but it could mean students are engaged in activities such as making a collage, building a model or role-playing. Hodson (1988) beholds all activities and learning methods where the students are active as practical work.

![Figure 3: Edited picture from Hodson (1988), illustrating different types of concepts as subsets of teaching and learning methods](image)

Abrahams and Reiss (2012) use a somewhat stricter definition of the commonly occurring term practical work, by seeing the concept as an overarching term that refers to all types of science teaching and learning, where students that are working alone or in small groups are handling equipment and/or real artefacts and materiel. In this thesis, I include all that Abrahams and Reiss define as practical work as being laboratory work, where the student becomes the actor and the teacher becomes the organiser and observer and where students’ work are framed by a specific assignment.
The development of laboratory work as a teaching and learning method

Ever since its introduction in the 19th century, laboratory work has continued to raise a debate concerning its role in science education. Even so, it has withstood a prominent place in the science classroom. In a review of the cumulated research concerning laboratory work up until 1980, Hofstein and Lunetta (1980) cite a report from 1970 in which the Commission of Professional Standards and Practices of the National Science Teacher Association made the following statement:

…That the experience possible for students in the laboratory situation should be an integral part of any science course, has come to have a wide acceptance in science teaching. What the best kind of experiences are, however and how these may be blended with more conventional classwork, has not yet been objectively evaluated to the extent that a clear direction based on research is available for teachers.

Hofstein and Lunetta’s (1980) objective was to summarise and critically review the outcomes from the research field in relation to the history and goals of laboratory work in science teaching, its effectiveness and to identify areas that demanded further research. Close to forty years has passed since Hofstein and Lunetta wrote this review of research concerning laboratory work’s role in science education. It is striking that these questions are still under scrutiny, waiting to be answered. The school, as we know it, with its students and teachers is an integral part of our society. Therefore, the ongoing development and changes in society also affect our view of teaching and learning. The object in focus for research in science education is thus not static but under constant change to cohere with the overall progress and demands of humanity. This is one reason why the identified areas of research emphasised by Hofstein and Lunetta (1980) are equally important today as well as in the future. In their review, Hofstein and Lunetta (1980) noticed a shift from the period following World War I, where laboratory activities were mainly used for confirming theory taught by a teacher, up until the 1960s where new science curriculums emphasised more the process of science and development of higher cognitive skills. Through these reforms, laboratory work’s role was strengthened to constitute the foundation from which the contemporary science teaching departed (Tamir, 1977). During the two decades that followed, critical voices from the research society began to arise. The effectiveness of laboratory work, in terms of learning outcomes in relation to costs and time consumption, was questioned. Studies based on paper and pencil tests did not measure any
significant improvement in learning outcomes, in favour of students who practised laboratory work (Hofstein & Lunetta, 1980). More targeted research was requested by Hofstein and Lunetta (1980), as they believed that data were insufficient to convincingly confirm or reject some of the hypotheses stated about the effectiveness of laboratory work as a teaching and learning method. Through their literature review, it became apparent that learning goals for laboratory work in general were synonymous with science teaching goals. Hofstein and Lunetta (1980) concluded in their summary that it was crucial to isolate and define explicit goals for laboratory work within science education.

The aims and goals of practical work

Since the Hofstein and Lunetta (1980) literature review was written, the science education community has grown considerably; thus, new social scientific research methodologies enable deeper analysis of questions concerning practical work in science education. In 1995, an extensive research project in Europe began, (Séré, 2002) "Labwork in Science Education" (LSE). The purpose of this project was to clarify the differences in aims for laboratory work and to gather information that may be relevant to the design of effective laboratory work in science education. Research groups from seven countries (Denmark, Germany, Britain, France, Greece, Italy and Spain) participated in the project. Studies were conducted at upper secondary school and at university level in biology, physics and chemistry. The outcomes showed that there were large differences between countries, in terms of how much time was devoted to experiments. However, there were no major variations in how laboratory work was performed. According to Séré (2002), the studies indicated that the main purpose of the laboratory work from a teacher’s perspective was to better understand the theory and link theory to practice. Through the years a lot of research studies has focused on identifying the aims of laboratory work (see e.g. A Hofstein & Lunetta, 2004; Högström, Ottander, & Benckert, 2006; Lazarowitz & Tamir, 1994). Jenkins (1999) identifies three main categories of aims: cognitive and affective aims and aims concerned with the acquisition of technique and manual skills. Aims categorised as cognitive, address students’ development of knowledge and understanding. In this aspect, laboratory work can be used to help students make links between theory and practice. Students’ interpretations of the taught models, used to explain theory, can be tested and re-evaluated through such laboratory work, thus, improving students’ conceptual understanding. Laboratory work used to motivate and increase students’ interest in science relates more to aims of affective character, according to Jenkins.
The skill category involves laboratory work that aims to allow students opportunity to practise: handling special equipment, using standard techniques, comprehension and execution of instructions.

All this different possible aims show the potential and versatility of using laboratory work as a learning and teaching method in science education. With its broad usefulness comes the risk that educators and teachers implement laboratory work without truly questioning its educational impact. Several of the above-mentioned aims could be automatically addressed just by routinely performing laboratory work. However, this is not sufficient as the real effects of students’ learning are shown to be scarce. Abrahams and Millar (2008) explored the effectiveness of practical work, where teachers’ focus was predominantly on developing students’ scientific knowledge. The results showed that the practical work was generally effective in getting students to do what was intended but significantly less effective in getting students to use the intended scientific ideas to guide their actions and reflect upon the collected data. The cognitive challenge, in terms of linking observables to ideas failed to appear (Abraham & Millar, 2008). Hodson (2014) believes that successful pedagogy depends crucially on teachers being clear about the purpose of each learning experience and refining their approach to improve students’ learning outcomes. Hart, Mulhall, Berry, Loughran and Gunstone (2000) claim that students are well aware of a specific laboratory works’ aim, as such information usually is given as the opening line of the teacher’s introduction. In contrast, the teachers’ purpose, why a specific exercise is chosen, is usually left unknown for the students (Gunnarsson, 2008). Jacobsen (2010) showed that students’ learning outcomes from the laboratory work could be improved, if teachers declare what students are intended to learn besides just being told what to do. Johansson and Wickman (2012) distinguish between proximate purposes and ultimate purposes, where proximate purposes relate to more student-centred purposes, and ultimate purposes are reserved for the more general goals of teaching. Together, these two purposes constitute the organising purposes of a teaching sequence. Johansson and Wickman (2012) state that what students are offered in terms of learning is dependent on whether purpose of organising and use of language are made continuous. I agree with these authors, but based on the results of this thesis I believe that students’ communication needs to be emphasised explicitly as an overarching aim for teachers and students’ laboratory work, something that I will return to and elaborate further, later on in this thesis.
Different forms of laboratory work

To successfully attain certain learning goals, teachers need to choose approaches that are well suited for the task (Hodson, 2014). The actual design of the laboratory work thus becomes essential. Different forms of laboratory work are often associated with the term degrees of freedom. A framework was presented by Schwab (1962) and further elaborated by Herron (1971), which describes four levels of guidance for the science laboratory (see Table 1). These levels, or degrees of freedom, indicate how much influence students have on the actual design and implementation of the laboratory work. Activities at level 0 are mainly used to verify that taught theory is in alignment with observations made. Laboratory exercises with higher degrees of freedom are usually entitled as open laboratory work.

Table 1: Level of guidance in a laboratory exercise (Herron, 1971).

<table>
<thead>
<tr>
<th>Level</th>
<th>Problem</th>
<th>Methods</th>
<th>Interpretations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Given</td>
<td>Given</td>
<td>Given</td>
</tr>
<tr>
<td>1</td>
<td>Given</td>
<td>Given</td>
<td>Open</td>
</tr>
<tr>
<td>2</td>
<td>Given</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>3</td>
<td>Open</td>
<td>Open</td>
<td>Open</td>
</tr>
</tbody>
</table>

Herron (1971) asserts that teachers could better match activities to students’ abilities, needs and expectations by using the scheme. The pros and cons of these different approaches have been debated heavily ever since among researchers in the field. Domin (1999) presented an alternative way of categorising different types of laboratory work. Four different styles of laboratory work were identified through the use of three indicators: Result, Approach and Procedure. The laboratory work’s result can initially be predetermined or unknown to students and occasionally also to the teacher. The approach can either be deductive or inductive. A deductive approach implies that students explore a known theory or phenomena and test if that theory is valid in a given circumstance. An inductive approach involves students seeking patterns in the data and constructing a theory based on their observations and experiences. The difference between Schwab’s (1962) framework and that of Domin (1999) is in how the indicator method is defined (see Table 2).
Table 2: Four styles of laboratory work according to (Domin, 1999).

<table>
<thead>
<tr>
<th>Style</th>
<th>Result</th>
<th>Approach</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expository</td>
<td>Predetermined</td>
<td>Deductive</td>
<td>Given</td>
</tr>
<tr>
<td>Inquiry</td>
<td>Unknown</td>
<td>Inductive</td>
<td>Student generated</td>
</tr>
<tr>
<td>Discovery</td>
<td>Predetermined</td>
<td>Inductive</td>
<td>Given</td>
</tr>
<tr>
<td>Problem-based</td>
<td>Predetermined</td>
<td>Deductive</td>
<td>Student generated</td>
</tr>
</tbody>
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Throughout history, laboratory work at level 0 has been the most common way of performing laboratory work (Herron, 1971; Abraham & Millar, 2008). This form of laboratory exercises is also often referred to as closed labs, expository labs or even cookbook labs, where students are given excessively detailed instructions that allow them to merely follow a recipe without having to think about what they are doing (Royuk & Brooks, 2003). The critics’ main argument against this type of exercise is that it fails to realistically model actual science where instead the thorough instructions make students tune out and not learn as well (Royuk & Brooks, 2003). Domin (1999) is of the same opinion and uses Bloom’s taxonomy of educational objectives to clarify the problem. The taxonomy is a hierarchical representation of six cognitive processes (starting at the bottom): knowledge, comprehension, application, analysis, synthesis and evaluation. Domin (1999) states that such classification is dichotomised into lower- and higher-order mental processes. Behaviours that would exemplify lower levels of cognition could, according to Domin (1999) include, remembering, recognising or applying a learned rule. Examples of high order thinking could be behaviours such as inferring, planning or appraising. In an analysis of laboratory manuals, Domin (1999) concluded that a majority of them required students to predominantly operate at the three lower levels of Bloom’s taxonomy. No activities required students to operate at the three higher cognitive levels, that is, analysis, synthesis or evaluation. This result from chemistry education is, according to Domin (1999), consistent with content analysis of laboratory work from biology and physics. Despite the criticism, laboratory work of closed character continues to be the most common way of doing practical work. One reason for this is that such form of activities can be performed by large number of students simultaneously with little involvement from the teacher. Moreover, the teacher can treat all students as a unit and knows exactly what students are doing and what types of results to be expected.
In contrast to the closed labs is the inquiry or open-inquiry laboratory work activities that have, as an object for research, grown immensely to become a research field of its own within science education. The expression *inquiry* has, in science education research, become synonymous with laboratory work, where students are in more control of the laboratory work. An inquiry approach is inductive and has an undetermined outcome. Students are expected to formulate the problem and generate their own procedure.

Lederman, Antink and Bartos (2014) stress that an inquiry extends beyond the mere development of different types of process skills, such as: observing, inferring, classifying, predicting, measuring, questioning, interpreting and analysing data. Inquiry also includes scientific reasoning and critical thinking to develop scientific knowledge. Wells (1999) asserts that inquiry also indicates a stance towards ideas and experiences, through a willingness to wonder, ask questions and to seek to understand by collaborating with others in an attempt to find answers. Domin (1999) claims that if inquiry is done properly, it gives students opportunities to engage in authentic investigative processes. At the same time, he is keen on emphasising that performing an inquiry-based activity is not the same as performing real scientific inquiry. Domin (1999) tries to shatter the myth that doing inquiry-based activities aims at placing the students in the role of real scientists. Domin (1999) states that students who participate in an inquiry-based learning activity are given the opportunity to learn the same concepts and principles that scientists learned as students, as well as learning about the processes and methods of science.

Ever since a constructivist perspective of education started to permute the education system in the 1970s, where students’ own curiosity was the incitement for learning through an investigative approach, the inquiry-based approach has been advocated by many researchers (see e.g. Duschl & Grandy, 2008). Despite a broad promotion from researchers and curriculum makers in favour of adopting and implementing inquiry as a teaching and learning method, inquiry is rarely implemented in schools (Krämer, Nessler, & Schlüter, 2015).

Contradicting a large number of researchers proclaiming the inquiry approach, are also researchers who advocate a contrasting opinion. Kirschner, Sweller and Clark (2006) are utterly critical to laboratory work approaches with minimal guidance. They believe that those who encourage an open inquiry methodological approach do so based on two assumptions:
First, they challenge students to solve “authentic” problems or acquire complex knowledge in information-rich settings based on the assumption that having learners construct their own solutions leads to the most effective learning experience. Second, they appear to assume that knowledge can best be acquired through experience based on the procedures of the discipline (i.e., seeing the pedagogic content of the learning experience as identical to the methods and processes or epistemology of the discipline being studied. (Kirschner et al., 2006 p. 76)

Kirschner et al. (2006) found that there is a vast body of empirical research that shows the superiority of guidance, specially designed to support the cognitive processing necessary for learning. They claim that a minimally guided approach stands in contrast to the structures that constitute the human cognitive architecture. In the article, Hmelo-Silver, Duncan, and Chinn (2007) disagree with Kirschner et al. (2006) and claim that inquiry learning and problem-based learning on the contrary are highly structured. Hmelo-Silver et al. (2007) feel that Kirschner et al. have mistakenly conflated problem-based learning and inquiry learning with discovery learning. Hmelo-Silver et al. (2007) make a claim based on research that inquiry learning and problem-based learning can foster deep and meaningful learning. They believe that students may discover information when they themselves experience a need for such information. A short lecture or demonstration then helps students to progress with their investigation or problem-solving. Hmelo-Silver et al. (2007) claim that such just-in-time direct instructions promote knowledge construction, which students later on can use in similar situations. In the discussion section, I will address and elaborate on my thoughts and conclusions concerning different methods of implementing laboratory work in physics, based on the outcomes of my own research.
The importance of communication in physics education

Contemporary science teaching and learning have a strong focus on activity, investigation, materials and equipment, which according to Hackling, Smith and Murcia (2010) has a physical and concrete presence in the classroom. However it is through talk, the most fundamental and commonly overlooked of classrooms elements, that teachers and students are able to work on ideas and develop understandings (Hackling et al., 2010). The importance of using discussions in the classroom is advocated by Lemke (1990) who states that ‘learning science means learning to talk science’. With this well cited statement, Lemke (1990) refers not only to talking about science, but emphasises that it also means doing science through the medium of language. Mortimer and Scott (2003) believe that talk is the central mode of communication in the science classroom, as the students are introduced to the social language of school science. When Edwards and Mercer (1987) stress that two-thirds of the lesson time is generally used for talk and that two-thirds of this time is the teacher’s talk, it becomes evident that the time used for students to discuss physics among each other becomes utterly important. Lemke (1990) advocates that teachers leave the traditional triadic dialogue, where the teacher asks questions, students answer, whereupon the teacher evaluates and corrects the answer. This type of dialog gives students very little opportunities for initiative and possibilities to take control of the discussions (Lemke, 1990). Bennett, Hogarth, Lubben, Campbell and Robinson (2010) instead advocate for the use of small group discussions that can help students explore their ideas and together develop more valid scientific ideas and explanations. Based on the literature above, I firmly believe that the laboratory work and its environment can act as an arena, where students can better discuss physics unconditionally using their own terms. Through well-designed laboratory work, where students are usually working with peers, opportunities for deeper discussions naturally occur. With that said, I feel obligated to clarify that I do not diminish the importance of a teacher led lesson, where the teacher speaks the language of science. If students are expected to embrace the language of physics, they must also be subjected to it and hear it, from persons who speak it fluently.

The school physics discourse at upper secondary level is a subset of the language domain that adolescents seldom encounter or use in the everyday language outside of the science classroom. For a student to become accustomed to such a discourse, it means being introduced to concepts, theories, physics laws and ways of working with science. Airey and Linder (2009) express this as ‘…students need to become fluent in a critical constellation of the different semiotic resources or modes of disciplinary discourse…’ (Airey & Linder, 2009,
p. 28). With modes, Airey and Linder (2009) intend, for example, spoken and written language, mathematics, gestures, images (including pictures, graphs and diagrams) and laboratory equipment. The Swedish upper secondary school physics curricula also implicitly highlights the importance of addressing and incorporating these resources into the physics education (see Swedish National School Agency, 2011). Based on my own experience, there is a considerable gap between the physics courses taught at compulsory school levels and physics courses given at Swedish upper secondary school science programmes, in terms of presenting physics using a mathematical backdrop. The mathematical language in combination with the strict definitions of concepts contributes to making physics appear as an isolated and foreign discourse, difficult for students to access. Several concepts, for example, work and force, are well known to students in their everyday life but have another meaning or a more strict definition when used in a physics context. The distinction between ‘everyday’ and ‘scientific’ ways of talking is something that students need to recognise and accept, if they are expected to fully embrace the physics discourse. Students do not need to give up their everyday knowledge, but they need to develop an alternative way of talking and thinking about the natural world (Scott, 2008). According to Scott (2008), learning should ideally engage students in making connections between the everyday view and the scientific view, through a raised awareness of similarities and differences between the two views. Scott (2008) denotes this as meaningful learning, which stands in contrast to rote learning, where the scientific view is related to memory but is not integrated with existing ideas.

In terms of laboratory work, Tiberghien, Veillard, Le Maréchal, Buty and Millar (2001) express a similar view, as they maintain that the main purpose of all laboratory work should be for students to make links between their observations and existing ideas. The language here becomes an important tool in such a process. Mercer and Littleton (2007) claim that language is the most flexible and creative of the meaning making tools available and state that ‘becoming an educated person necessarily involves learning some special ways of using language: and language is also a teacher’s main pedagogical tool. For these reasons, language, and especially spoken dialogue, deserves some special attention’ (Mercer & Littleton, 2007, p. 2). Bakhtin’s (1986) view of language is that meaning is something that is created in the dialog and in the interaction between the speaker and the receiver. He finds that it is not the individual but rather the individuals together in the group that create meaning. (Bakhtin, 1981)
In this thesis, with the aim to explore students’ laboratory work with regard to its design and influence on communication, students’ language comes into focus from two different perspectives. Through students’ communication, I can follow how students make progress in their task and interact during the laboratory work. Students’ communication here works like a lens through which a deeper understanding of what learning possibilities the laboratory work has to offer. Moreover, with the view that students’ communication is an important tool for students’ learning, exploration of how the design of the laboratory work affects students’ communication is enabled. Based on the previous literature cited above, communication is here defined as referring to the joint understanding students create through collaboration during laboratory inquiry with regard to talk, content and interaction during activities.

**Students’ communication in small groups**

In recent years, there has been a rapidly growing interest in study of students’ conversations and argumentation (see e.g. Duschl & Osborne, 2002; Evagorou & Osborne, 2013; Kind, Kind, Hofstein, & Wilson, 2011). Studies in argumentation are often undertaken with the Toulmin Argumentation Pattern (TAP) model (Toulmin, 2003).

Also, Mortimer and Scott (2003) notice the growing focus on argumentation in science education and withhold the importance of not missing central aspects in the authentic teaching as it is applied in most classrooms. Mortimer and Scott (2003) feel that more studies concerning traditional classroom talk is needed before new areas are further developed. I do not question that there are benefits of actively using argumentation as a teaching and learning method in the physics classroom, which also requires further research. However, the study of students’ use of argumentation is not my foremost interest in this thesis. Instead, my interest concerns how students use communication as a media to progress and make meaning during the laboratory work.

The study of students’ conversation when working in small groups began with Barnes and Todd (1977). They set out to examine the relationship between short-term, small-scale aspects of social interaction of small groups and the cognitive strategies generated in the course of such interaction. By doing so, they made a number of assumptions about cognition and its relationship to speech. Through the assumption that speech functions as a means of communicating with other people, they could investigate the interplay between
cognitive and communicative functions of speech in contexts planned for learning. In their study, they also assumed that one of the means by which youths achieve hypothetico-deductive thinking, formal operations, is through internalising the viewpoints of other people, and that such internalisation takes place in the course of dialogues in which different viewpoints are interrelated through verbal interaction with other students (Barnes & Todd, 1977). They expected that the learners, the task and the social situation in which the learning took place, would affect the way in which language was used. To take account for these affects, they decided to work with teachers of several different subjects. Over a period of twelve months, they made recordings of secondary school children talking in small groups, in which a total of 56 children participated. The topics students were asked to discus were all covered in class and varied in character depending on the subject. Barnes and Todd found that students working in pairs engaged in exploratory talks during laboratory activities to solve conceptual problems and that they made specific discursive moves to proceed towards conclusions and agreements. According to Barnes and Todd, the exploratory talks include the characteristics of hesitations, changes of direction, tentativeness shown in intonation, assertion and questions in the hypothetical modality (Barnes & Todd, 1977).

Their interests were not to find out how all dialogue was structured but to recognise structures in dialogue, which contributed to learning. Based on repeated listening to the audiotapes and analysis of transcripts, they come to a way of categorising students’ talk grounded in the data. A distinction was made between interactive and cognitive aspects of speech events, which were subdivided into four functional components, based on the work of Halliday (1970). Interaction was divided into Discursive Moves (level one) and Social Skills (level two). Cognition was divided into Logical Process (level one) and Cognitive Strategies (level two) (Barnes & Todd, 1977).

Discursive Moves ‘include those characteristics which any discourse must have in order to be coherent and sequential: without such sequential relationships there would not be a conversation but only a list of sentences’ (Barnes & Todd, 1977 p. 19 ). They emphasise that such a system of discursive moves could be made more exhaustive (see Table 3).
Barnes and Todd (1977) suggested that by doing a content analysis of a topic and then identifying for each utterance, both its logical relationship to a previous utterance and its content category could be made. By doing so they presumed that it would be possible to schematically represent the pattern of thought development in a discussion. In their extensive scheme for analysing group talk and the social and cognitive functions, the discourse moves guide how the talk in small groups becomes exploratory. The students’ informal reasoning during practical work showed distinctive discursive moves, and on a cognitive level student communication also showed how the content was negotiated.

Mercer (1995) describes three ways of talking and reasoning and presents these as three analytical categories, which are useful for the study of discourse when students talk in small groups.

- Disputational talk could be described as individualised decision-making in contrast to searching for agreement and common knowledge. This discourse is based on disagreement and exchanges of assertions and counter assertions and is characterised by a debate.
Cumulative talk is based on repetition, confirmation and elaboration, and like exploratory talk, it allows for construction of common knowledge by accumulation. In the cumulative discourse, the speakers build positively and uncritically on what others have said.

Exploratory talk is the valuable form of conversation in which statements and suggestions are offered for joint consideration, and the speakers show critical and constructive engagement with each other’s ideas.

The work in this thesis can be considered as a continuation of the work done by Barnes and Todd, since their thoughts and initial approach to study students’ talk in small groups, together with the work done by Mercer (1995), constitute the backbone of the analysis undertaken in this thesis.

Learning through working in small groups

Learning is, according to Lemke (1990), a social and cultural process in which language plays an important role. Enghag, Gustafsson and Jonsson (2004) introduced CRP (Context Rich Problems) in order to study how group discussions influence students’ learning and their ownership of learning. Their focus was on the group’s behaviour and individual activities in the group, specifically, how this reflects in engagement of the task and perception of the question at issues, and any difficulties in reasoning and understanding of physics concepts. The concept students’ ownership of learning here includes the groups’ constellation and the actual instructional setting, such as: content, question, planning, performance, result and presentation (Enghag et al., 2004). According to Enghag et al. (2004), main point with the concept of ownership is communication, where students are given opportunities to discuss with others and to allow for emergence of own questions. In their study, they found that in small groups working with CRP, main part of the time was used for talking physics even in low performing groups. They observed how students in high performing groups used exploratory talk, and they taught each other until they all agreed. Enghag et al. (2004) stress the importance of having the teacher stimulate the discussion in the lower performing groups so students can address the problem more deeply. They concluded that giving students the possibility to communicate in reflective and exploratory talks around a physics problem makes students realise the individual difficulties they have with the physics content. I firmly believe that the benefits of working in small groups, described by Enghag et al. (2004) also applies to the context of physics laboratory work.
Students’ ownership of learning could thus be expected to increase with the degree of openness. Henriksen and Angell (2010) argue for the use of electronic audience response systems (ARS) in combination with the active use of student small-group discussions. In their study, they see how the implementation of ARS problems functions as an incentive for students to practise talking physics. In their analysis, they noticed how ‘students’ discussion often proceed in a seemingly haphazard fashion with frequent instances of aborted reasoning, unfinished sentences and fumbling use of physics terminology’ (Henriksen & Angell, 2010 p. 283). This is, from my perspective, a clear example of how students engage in an exploratory talk, where students together strive to understand and progress with the task.

Johnson and Johnson (1999) assert that ‘working together to achieve a common goal produces higher achievement and greater productivity than those working alone’ (ibid, p. 11). They elaborate on the advantages of cooperative learning and stress that five basics elements are essential and need to be included in order for a lesson to be cooperative: 1 – **Positive interdependence**, which means that the individual benefits from the group’s work and the group benefits from the individuals’ work. This promotes a situation in which students’ work together in small groups increases the learning of all collaborators. Johnson and Johnson (1999) believe that positive interdependence is the heart of cooperative learning, which must be established through mutual learning goals. 2 – **Individual accountability** relates to the importance of individuals in the group being aware of who or which needs more assistance, support and encouragement in completing the assignment. 3 – **Face to Face Promotive Interaction** concerns students’ ability to promote each other’s learning. Here, Johnson and Johnson (1999) include the concept of orally explaining how to solve problems, discussing the nature of concepts being learned and connecting present with past learning. They emphasise that accountability to peers, the ability to influence each other’s reasoning, conclusions and social support, all increase through the interaction among the students. For this to happen, they stress that the ideal size of a group is two to four students. 4 – **Social Skills** is thus an important ability that students must possess in order for effective cooperative learning to occur. Students must therefore be taught the social skills for high quality cooperation and also be motivated to use them. According to Johnson and Johnson (1999), it is equally important to teach skills in decision-making, building trust, communication and even conflict management as well as the academic content. The last of the basic elements that need to be included for effective cooperative learning to take place is 5 – **Group Processing**, which exists when students discuss how well they are achieving their goals. Johnson and Johnson (1999) claim that students need
to be given the time and procedures for analysing how well their groups are functioning, making such reflections specific rather then vague. This research highlights the importance of understanding and incorporating cooperative learning as a teaching and learning method, which also becomes an additional ingredient to the complexity of designing effective laboratory work. To assume that students working in small groups are automatically involved in deep exploratory talks is therefore not realistic. Likewise, it is not realistic to expect students to know how to design and implement laboratory work based merely on their experiences of doing physics laboratory work. Students need to also be trained in how to effectively achieve cooperative learning as well as be trained in the process of using scientific approaches to acquire new knowledge.

**Language as a social mode of thinking**

In my efforts to explore students’ conversations in the context of the laboratory work it becomes essential to also consider students’ talk as thoughts. Mercer (1995) describes language as a social mode of thinking. He draws attention to two important ways in which language is related to thought. One is that language is a vital means by which we represent our own thoughts to ourselves, what he refers to as the cultural function (communicating). Mercer (1995) believes that language is our essential tool that we use to share experiences and so to collectively, jointly, make sense of it. Through the use of language, experiences can be transformed into knowledge and understanding. Mercer (1995) emphasises that language, both spoken and written, is not just means by which individuals can formulate ideas and communicate them, it is also a means for people to think and learn together.

**Research about kinematics in physics**

Students’ perceptions and understanding of forces and motion has caught many educational researchers interest. That also includes research on how laboratory work can be designed to address existing misconceptions (see e.g. Araujo, Veit, & Moreira, 2008; Bernhard, 2010; Hake, 1998; Lindwall & Lymer, 2008; Sokoloff, Laws, & Thornton, 2007; Thornton & Sokoloff, 1998). Microprocessor Based Labs (MBL) has been around since the late 80s. The development since then has progressed immensely and Sokoloff et al. (2007) states that the use of sensors are a powerful way for students to learn to understand the meaning of physical concepts. With the help of such sensors students can interactively discover and explore the concept of motion, by walking in front of a motion detector while the software shows the position, velocity and acceleration in real time. There are also probes to measure forces,
sound, magnetic field, current, voltage, temperature, pressure and other physical quantities. Sokoloff (2007) argues that by combining the results of physics education research and real time physics, students can acquire better conceptual understanding and obtain better laboratory skills. Royuk (2003) examined if there were significant differences in conceptual understanding in mechanics between students who participated in labs of cookbook character with MBL-technology, compared to students who experimented more interactively with MBL technology. The general perception that poor cookbook labs are not conducive to conceptual understanding is confirmed in Royuk and Brooks study. The results of the study also show that the use of new technologies like MBL does not automatically mean that students learn something. To ensure that new technologies can contribute with new knowledge and understanding, a new approach to the laboratory work must be considered. Bernhard (2010) successfully designed and implemented conceptual labs using similar technology, aimed at developing insightful learning. He thinks of laboratory work as an arena for further learning and not merely to confirm the theories and formulas that have already been presented at lectures. Bernhard (2010) concludes that well designed laboratory work or similar learning environments can contribute to insightful learning.

In this thesis, students performed laboratory work with the use of the above-mentioned technique (see papers I, II and III). The theme of the laboratory work on these occasions was uniformly accelerated motion. Students were asked to explore concepts such as position, distance, speed, velocity and acceleration. The laboratory work consisted of an activity where students were supposed to walk in front of a motion detector, whereupon the motion was simultaneously transformed to a position time graph on a computer screen. Our observations of these activities conform to the findings of Royuk and Brooks (2003). How students engage in the task and utilise the probe-ware equipment depends on the design of the laboratory task.
Theoretical Perspective

Waring (2012) denotes that all researchers need to understand that their research is framed by series of related assumptions, which are framed around ontology, epistemology, methodology and methods. Here, I will attempt to express and explain my own assumptions in relation to these four frames, which I have made during this work and that conclusively underpin my own theoretical positioning.

Ontology and epistemology positioning

During my earlier science studies to become a physics and mathematics teacher, I never truly considered that the form and nature of the social world could be perceived differently. Specifically, from realism, where the world exists in its current form independently of our own presence, to idealism where reality is neither objective nor singular but where different realities are constructed by individuals. Despite Waring's (2012) exhortation, I must admit that my own research project did not depart from a stance relating to the aforementioned assumptions. Instead, my thoughts in relation to these grounding questions are something that slowly but gradually have come to be of importance in my own work. Through the study of research literature in the field of laboratory work and later of communication in the classroom, a natural selection was made from which my own research builds upon. This selective process is partly a consequence of the fact that these authors’ expressed views cohere with my own thoughts and values. In that respect, my theoretical positioning is grounded in the literature that I have chosen to cite and build my work upon. Concerning ontology, I adhere to a critical realism view as I presume that the world does exist in its current form, with or without the existence of humanity, but that our knowledge is dependent on the theories and methods we use to explore its nature (Wallén, 1996). An epistemology assumption relates to knowledge. I chose to illuminate my view concerning the actual construction of knowledge through a comparison of different philosophical views of learning. From a historical perspective, the view of learning in the classroom has evolved from constructivism to the now contemporary sociocultural view of learning. The Swiss researcher Jean Piaget (1970) formulated the constructivism view of learning, which means that the individual him or herself creates or modifies knowledge of the surrounding world. Piaget was mainly interested in the development of children’s cognition. The constructivist view of learning has affected and formed the education since the beginning of the 70s, and especially in the natural science subjects. Elfström, Nilsson, Sterner and Wehner-Godée (2008) describe the constructivist view of humanly thinking and learning as an
individual that actively creates meaningfulness. In a pedagogical context, this implies that when a person studies and interacts with the surrounding world, both physical and conceptual, the person simultaneously creates a meaningful personal picture of the world (Elfström et al., 2008, p. 29). The Swedish school system has been highly influenced by this view and started to emphasise that younger children should be allowed to be active and explore things more on their own premises. The teacher should let the children be guided by their own curiosity. The underlying thought is that a child should understand content through his or her own actions. Focus should be placed on stimulating the person's own efforts and investigations. A teacher should not tell the child something that he or she could discover by himself or herself; thus, the inductive approach to learning is emphasised here (Elfström et al., 2008). The constructivist view implies that the individual child has already at an early stage comprehended his or her own knowledge and theories about science phenomena. The teacher must therefore design the teaching based on the child’s existing knowledge (Elfström et al., 2008). I want to stress the constructivist view, as its perspective of learning has had huge impact on science education. Through this view of learning, the role of laboratory work became more central as a teaching method, and the open inquiry approach gradually emerged. The criticism of the constructivist perspective, which I share, has been on the focus on individual child’s learning without fully taking into account that learning is related to a social context.

That learning takes place in a social and cultural context is central in the sociocultural perspective of learning. The founder of the sociocultural perspective of learning was Russian psychologist Lev Vygotsky. Essential to his perspective is the idea that development and learning involve a passage from social contexts to individual understanding (Vygostky, 1978). Mercer and Littleton (2007) believe that Vygotsky conceptualised social interaction as being core of the development process, where cognitive development is seen as a constructive process. The child is however not alone in such a process; instead, the construction of knowledge is essentially a social activity. The child’s interaction with other people mediates the child’s encounters with the surrounding world. Mortimer and Scott (2003) explain Vygostky’s (1978) sociocultural view as a transition of new ideas from social to individual planes. New ideas are met in social situations where those ideas are exchanged and rehearsed between people, using a variety of modes of communication, such as talk, gestures, writings, visual images and action. The social plane can, according to Mortimer and Scott (2003), be constituted by a teacher working with the students in the school, or it may involve a group of students meeting and
talking in another context. In such a social event, each participant is able to reflect on, and make sense of what is being said. Mortimer and Scott (2003) claim that different modes of communication constitute the tools needed for individual thinking. Through transition from the social to individual plane, communication becomes internalised and provides the means for individual thinking (Mortimer & Scott, 2003, p. 10). According to Vygotsky (1978), it is important that students have some everyday idea linked to the concept, from which new rehearsed ideas evolve from interaction if students are expected to learn new scientific concepts. Barnes and Todd (1995) express a similar view, where learning focuses on the learner’s reinterpretation of existing knowledge, where talk is used as a tool to rephrase thoughts and ideas. From a sociocultural perspective of thinking and learning, human language is thus central. Säljö and Wyndhamn (2012) state that language is without comparison the most important mechanism by which humans can develop, test and communicate views of the world.

The work of this thesis originates in what different forms of laboratory work have to offer physics students at upper secondary schools in their learning and how effective these different forms are in relation to each other. Through analysis of extensive data collection, consisting of interviews, field notes and video recordings of students performing practical work, my focus of interest gradually shifted towards concerning students’ communication in the context of physics laboratory work. When listening to students’ discussions, I started to fully realise the value and opportunity students’ dialog possessed in terms of sharing understanding and creating new knowledge. It became evident that the environment the laboratory work constitutes is an ideal setting for students to involve themselves in open non-judgemental physics discussions. As mentioned earlier, the purpose of using laboratory work in science education is multifaceted. It is both used to teach students the core physics content and how to perform investigations and develop critical thinking (Wickman, 2002). Laboratory work gives students possibilities to explore and physically interact with the nature surrounding them in a constructivist sense, as recommended by Jean Piaget, but it also enables students to interact with their peers and together make sense of their observations through the use of language. This study is undertaken from a sociocultural perspective of learning, where students’ theoretical and practical development in physics is seen as a result of social interaction and the use of language (Mercer, 2000, 1995; Mortimer & Scott, 2003; Vygotsky, 1978).
Methodology considerations

The term methodology is often mixed with the term method. Methodical assumptions are reflections of the ontological and epistemological assumptions (Waring, 2012). Methodology is the justification for using a particular research method, whereas method concerns how the data actually have been collected and further analysed. Throughout the relatively short history of research in science education, there has been a polarisation between the two aforementioned approaches to research. The quantitative approach has a tradition of following the natural sciences, such as physics, chemistry and biology. Devoted researchers of the quantitative approach believed that this was the only way to conduct serious research and questioned the value of qualitative research (Robson, 2011). Researchers advocating the qualitative approach likewise dismissed the quantitative design, as it only involved crunching numbers and relying on statistics. The quantitative approach was no way of understanding anything worthwhile about people and their problems (Robson, 2011). This polarised view now seems to slowly begin to dissolve according to Robson (2011), who thinks that there is a growing recognition of the values in combining elements of the two different methodologies. As a result, the use of a mixed method has become more frequently applied, where both a quantitative and qualitative approach is used. However, a further comparison between the two methods is here necessary, as there are substantial differences between these approaches. In this thesis, I have used both a quantitative approach and qualitative approach when analysing students’ talk.

The main difference between the quantitative and the qualitative approach lies in the flexibility. The quantitative approach is much more rigid in its character, where structured observations can be used to quantify variation and predict causal relationships. Mercer (2010) implies that a quantitative method usually uses a coding scheme to reduce the data of transcribed talk to counts of a specified sets of features. Systematic observation is often used when studying classroom interaction, which involves allocating observed talk to a set of previously specified categories. The aim with such observations is usually to provide quantitative results, which can be subjected to statistical analysis (Neil Mercer, 2010). It can be, for example, number of talk-turns between teacher and students, or number of different categories of questions asked by the teacher or the students. A specific characteristic of a systematic observation is that the research question and initial observations of the interaction are used to construct categories, into which relevant talk can be classified. Mercer (2010) stresses that many experimental studies of collaborative interactions use
statistical techniques to ascertain whether there is any evidence of links between the relative occurrence of particular features of classroom talk and students gaining knowledge. An advantage of quantitative approach is that a lot of data can be analysed quickly, without having to process all data in detail. Mercer (2010) also elaborates some of the limitations of quantitative methods. He feels that the most serious are the problems of dealing with uncertainty of meanings, the temporal development of meanings, and that the same utterances can have different functions. Moreover, Mercer stresses that there also are difficulties in determining the appropriate size of the unit of analysis to be coded, as the phenomenon under study involves a continual, evolutionary process of meaning making between the students. A quantitative approach involving categorical coding schemes, are according to Mercer (2010), generally inappropriate tools to use without also using a qualitative analysis, if the purpose is to understand the process of teachers and students’ learning.

In order to gain a fuller understanding of the processes of collaborative work, researchers need methods, which recognise that collaborative work is typically more than just brief, time-limited, localized sessions of joint activity.

(Mercer, 2010 p. 5)

In paper II, the method applied was quantitative to its nature. The purpose was to better understand the extent to which the actual design of the physics laboratory work influenced students’ communication. In this study, the interest was not in the individual students’ way of talking or executing the given task, or how students understand physics. Instead, the aim was more overarching, where we searched for statistical facts, to be able to see an existence of a correlation between the design of laboratory work and students’ communication. The descriptive quantitative analysis that was conducted in paper I creates an understanding of how the design of the laboratory work influences students’ communication, from which a deeper analysis of students’ talk was undertaken.

The aim with using a qualitative method when studying students’ interaction is to find patterns and investigate the qualitative aspect of spoken interactions (Neil Mercer, 2010). One of the advantages of using a qualitative method when studying students’ interaction is that the development of joint understanding, or the existence and persistence of different opinions, can be pursued through the continuous data of recorded and transcribed talk. Moreover, the qualitative analysis is more flexible than the quantitative method, as it is possible to expand
to also include new aspects of communication that emerge in the analytical process. The transcribed conversations can also be used to show concrete examples of the analysis (Mercer, 2010). In papers I, III and IV, a qualitative method was therefore used to find answers to research questions concerning how students' interaction evolved during the physics laboratory work. In paper I, the aim was to apply an analytical instrument, primarily designed for analysing laboratory instructions, to explore a physics activity’s effectiveness. The context here was important, as the analysis was solely preformed on a closed laboratory activity. There was a need to better understand how individual students acted and experienced the situation at hand.

In paper III, the aim was to describe in detail how students use talk during laboratory work at both a linguistic and cognitive level in relation to interaction and content. There was a need to understand phenomena in the special context of laboratory work. An inductive logic was used, starting from the data collection from which theoretical ideas and concepts emerged. In paper IV, the aim was to explore how individuals in a group constellation contribute and together make decisions and thus made progress, through analysing students’ talk patterns. Drawbacks with the qualitative method are that the analysis is very time consuming, which limits the amount of data that can be analysed. The possibility to generalise the results is thus often difficult. A combination of the methods, so-called mixed methods, can therefore be a fruitful way to proceed. Papers II and III in this thesis build on the same data but are respectively analysed with a quantitative and qualitative method. The results presented in paper II created new questions that could only be answered through a new qualitative analysis of students’ interaction. The two papers combined give a richer and clearer picture of how students’ communication is structured and influenced by the design of physics laboratory works rather than the individual articles.

Method

The methods of inquiry used in this thesis are divided into two categories: data collection and analytical methods. The procedure of the four papers, namely, data collection will be described first, followed by explanation of the various analytical methods applied.
Data collections

All the data collection for this thesis was done at a Swedish upper secondary municipal school with a total of about 600 students. The school’s natural science and social science programmes dominate the curriculum but more practically oriented programmes also exists. Two classes in the science programme together with three physics teachers participated in this project. Three extensive data collections were made in these two classes during a period of two years. All students participating in the study were 16 to 17-years-old. The students were informed about ethical guidelines from the Swedish Research Council, and they had given their written permission to take part in this project. Students were informed that they could choose to interrupt taking part in the project at any time. Data have been handled confidentially during the research process. The four papers presented in this thesis, all stem from these three data collections.

All participating students in papers I – III attended at the science programme during their first year. The participating students in paper IV attended the science programme during their second year. At this school, laboratory work in physics was scheduled for 90 minutes, once every two weeks. During these laboratory physics lessons, the entire class was usually divided into half. While one-half of the class performed laboratory work in physics, the other half performed laboratory work in chemistry or biology. After 90 minutes, the students swapped subjects.

The teacher divided the students into groups of three to four students. The groups were placed in separate rooms to facilitate good audio and video recording. Usually one, occasionally two, video camera(s) was placed in the room to record students’ interaction. All students were gathered in the classroom during the teacher's introduction and summary of the laboratory work. These occasions were also video-recorded. Interviews with students were performed as group interviews, usually within one week after the laboratory work. The interviews were semi-structured, meaning that they revolved around the performed laboratory work but where students were given opportunities to more freely express their own experiences and views in relation to the work. Additionally, students’ laboratory reports were gathered in case a supplementary analysis was needed. Interviews with the teacher was performed just prior to and after a documented laboratory work session. Teacher interviews were also of semi-structured design, where the focus was on the teacher’s aim, purpose and expectations with the laboratory work. Thereafter, the teacher gave a summary of his or her impression concerning the implementation and outcome of the laboratory work. All interviews were video-recorded.
All the video recordings of students’ laboratory work and interviews with the teachers and students, which this thesis builds upon, were transcribed verbatim and further analysed using a video analysis computer programme, called Transana (Transana 2.60, 2016).

**Analysis methods**

In this thesis, the analytical approach varies in the different papers. However, all collected data were initially treated the same way. All of the video recordings were viewed several times, whereupon all, or selected parts of students’ interaction were transcribed verbatim, before a deeper analysis was performed. I will here motivate and describe the methods of analysis that have been used in the four separate papers.

**Paper I**

In paper I, the aim was to analyse the meaning of effectiveness of laboratory work, in relation to students’ learning experiences. The video-recorded laboratory work and interviews were analysed based on an instrument originally developed for use in the European Labwork in Science Education (LSE) Project in the late 1990s. Many different ways of classifying laboratory work and highlighting differences have been presented (see e.g. Domin, 1999; Herron, 1971; Tamir & Lunetta, 1978). Many of those schemes were designed to study the match between objectives of laboratory task and the stated curriculum goals. The analytical framework presented by Millar, Tiberghien and Le Maréchal (2002) aims instead at providing a general framework for investigating issues of effectiveness of laboratory work.

The analytical instrument consists of four different steps A-D (see Figure 4), where the first two steps concern the teacher’s intentions with the activity, in terms of what students are intended to do and learn. Millar et al.’s (2002) intention with the presented scheme is for teachers or researchers to be able to produce a profile of the labwork task being explored. They divide learning objectives (A) into two main groups: content and process, where content is concerned with some aspect of scientific knowledge, and process concerns learning the process of scientific enquiry. Content accommodates objectives such as learning a fact, concept, relationship, a theory/model or identifying objects and phenomena. The category Process accommodates objectives such as learning how to use equipment, carrying out a standard procedure, planning an investigation, processing data, or learning how to communicate the results (Millar et al., 2002). The second step (B) concerns the design of the task, in
terms of what students are expected to do. Millar et al. (2002) differentiate between what students are about to do with objects and what they are expected to do with ideas. With objects, Millar et al. (2002) refer to students’ practical use of materials and equipment. It can, for example, connote students making something, measuring something or observing something. With ideas, Millar et al. (2002) emphasise that students are also supposed to think about the real objects they are handling. Students may have to test a prediction, identify a relationship or propose an explanation (Millar et al., 2002). By reflecting on the design of the task, Millar et al. (2002) also include consideration about the openness of the task. Who decides what to do and how to do it? Is it the teacher, the students, or is it decided by discussion? The analytical structure (see Figure 4) is complemented with an extensive scheme, consisting of tables where a teacher or a researcher systematically can evaluate a labwork task. By ticking the applicable boxes, for each category under the two steps, an overall picture of what a specific laboratory task has to offer students appears.

Figure 4: The process of developing and evaluating a labwork task (Millar et al., 2002)
The last two steps, C-D, guide the analysis process towards what the students actually do and learn by carrying out the activity. By observing how students work and how they interact, it makes it possible to examine what they learned from the activity. The activity’s effectiveness can then be analysed from two aspects: 1) what students should do in relation to what they actually do and 2) students’ learning outcome in relation to the teacher’s intention. Tiberghien et al. (2001) emphasise that the most fundamental purpose of laboratory work is that students shall be able to connect what they see and do in practice, to develop a scientific understanding. The effectiveness of laboratory work can be considered from two levels, according to Millar (2009) (see Table 4).

Table 4: A laboratory task’s effectiveness at two levels (Millar, 2009)

<table>
<thead>
<tr>
<th>A practical activity is:</th>
<th>in the domain of objects and observables</th>
<th>in the domain of ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective at level 1</td>
<td>Students do what was intended with the objects and materials provided and observe what they were meant to observe</td>
<td>During the activity, students think about what they are doing and observing, using the ideas intended, or implicit in the activity</td>
</tr>
<tr>
<td>Effective at level 2</td>
<td>Students can later recall and describe what they did in the activity and what they observed</td>
<td>Students can later discuss the activity using the ideas it was aiming to develop, or which were implicit in it (and can perhaps show understanding of these ideas in other contexts)</td>
</tr>
</tbody>
</table>

It can be effective from the point of “doing”, level 1, and from the point of “learning”, level 2. In order for an activity to be effective at level 1, students must use equipment and proceed with the task as the teacher initially intended. If the laboratory activity should be considered effective in terms of learning at level 2, then Tiberghien et al. (2001) believes that students should be able to describe what they have done and observed, and they should be able to discuss the lab using the ideas that it was meant to develop in another context. This framework was used to analyse the effectiveness of the laboratory task presented in paper I. The analysis followed the four steps presented in Figure 4. Through an interview with the teacher and studying the written instruction, it verified the teacher’s different intentions and the design features of the task. Detailed analysis of the video recordings was used to explore students’
interaction. A short period after the labwork, an additional written test and interviews were used to establish students’ experiences and learning outcomes.

**Paper II**

In paper II, a quantitative approach was chosen to find answers to the research questions. Domin’s (1999) three descriptors, *Outcome, Approach and Procedure*, were used to distinguish and identify the character of the four laboratory workstations. An initial attempt was made to classify the workstations according to Schwab’s (1962) degrees of freedom; however, it turned out to be a blunt analytical instrument, in the sense that obvious differences between the laboratory workstations could be observed but were not identified through Schwab’s (1962) categories. When we started to investigate if students’ approach was deductive or inductive, a clearer differentiation between the different workshops appeared. Through repeated observations of video recordings of students’ work, we could see that students’ activities could be described in terms of five different types: *Planning, Preparing equipment, Collecting data, Processing data and Analysis of results*. These activities were then defined through a clear description. To analyse students’ communication, Mercer’s (1995) description of three different types of talk came in use.

Mercer (1995) describes three ways of talking and reasoning and presents these as three analytical categorises.

*Disputational talk*: - This type of talk between students is characterised by disagreement and individualised decision-making.

*Cumulative talk*: - Students do not question each other. Given statements are not challenged by others. The talk is build up by a common consensus where students confirm each other’s utterances.

*Exploratory talk*: - Is seen as the valuable form of conversation, where students show critical and constructive engagement in each other’s ideas. Alternative viewpoints are offered for joint consideration. Students ask for clarifications and search for a deeper understanding.

After each of the workstations was identified based on style of laboratory work, they were analysed with rigour, based on students’ activities and communication. The video recordings from each group’s work at each station were analysed in three steps.

I. The video recording was firstly divided into sequences based on which one of the five activities students were engaged in. Students could, for
example, start by using the first 4 minutes to plan their work, followed by 6 minutes to collect data and end their work by using 5 minutes to process their data.

II. In a second step of the analysis, each one of those activity sequences were further divided into shorter episodes, describing more specifically what students were doing and talking about at that moment of time. An episode could for example be where students attempt to measure a height or talk about a calculated results meaning.

III. Finally, each episode was coded for the three different types of talk students were engaged in at that moment of time.

The findings were presented as clustered staked column charts.

*Paper III*

In paper III, the same data collection as in paper II was revisited. The main purpose was now to analyse the data to explore in-depth the three different types of talk at both a linguistic and cognitive level. We wanted to find out what these different types of talk have to offer students, in terms of interaction and content. To answer the research questions, a discourse analysis, using a qualitative thematic approach was conducted, or a thematic discourse analysis, as called by Braun and Clarke (2006). A thematic analysis provides a flexible and useful research tool, which has the ability to provide a rich and detailed account of data (Braun & Clarke, 2006). Thematic analysis is a method for finding, analysing and reporting patterns within data. The term thematic discourse analysis refers to a wide range of pattern-type analysis of data, where patterns are identified as socially produced.

A thematic analysis starts parallel with the gathering of data. Basically, as soon as the researcher starts to notice and look for patterns of meaning and issues of potential interest in the data (Braun & Clarke, 2006). Braun and Clarke (2006) present a 6 step procedure to conduct a thematic analysis:

1. Familiarising yourself with the data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Producing the report

(Braun & Clarke, 2006 p. 87)

The analytical approach in paper III was deductive in the sense that the four cornerstones of the framework, the four guiding questions framed the investigation from the start: How do they speak? How do they act? What content is in focus? What purposes are expressed? However, it was inductive in
the sense that we searched for answers to the questions by conducting a thematic discourse analysis.

The first step involved transcribing the data, and repeatedly reading the data and noting ideas. In paper III, the video recordings had already been divided into shorter episodes in paper II based on activities students were engaged in, such as planning, preparing equipment, collecting data, processing data and analysis of results. The second step involved generating codes, or discursive moves, for the cumulative and disputational types of talk. Barnes and Todd (1977) had earlier identified moves for exploratory talk. Steps 2 and 3 involved searching for codes or moves through an iterative open coding process (Mayring, 2001), relating to the four questions. Steps 2 and 3 were repeated until no further moves could be identified. At steps 4 and 5, both researchers discussed the identified moves, whereupon some moves were merged; these moves were then categorised under the four main categories: Discursive moves, Action moves, Content moves and Purposive moves.

**Paper IV**

Discourse analysis is the study of language in use. There are many different approaches to discourse analysis (Gee, 2014). A sociocultural discourse analysis differs from linguistic analysis in being less concerned with the organisational structure of spoken language (Mercer, 2010). In some of these approaches, such as in paper IV, the analysis is focused on the content of the language, whereas the linguistic discourse pays more attention to the structure and grammar of language (Gee, 2014). In the discourse analysis performed in paper IV, we searched for underlying moves in the students’ conversations. These invisible moves build the conversation and make it coherent (Barnes & Todd, 1995). In paper IV, after the video recordings were transcribed verbatim and viewed repeatedly, the films were divided into shorter episodes based on overall topic of students’ conversations. Each episode in the transcript was subsequently analysed in four steps according to the model presented in paper III. The individual students’ moves in the four categories were identified and written down. This process enabled us to study individual student’s interaction at both a linguistic and cognitive level. In a fist step, the episode was analysed based on how students communicated. The conversation in the episode could be categorised into one of Mercer’s three types of talk, depending on the different discursive moves students took during the conversation. The episode was then analysed based on what purposes student’s expressed at a cognitive level.
Reliability, Validity and Generalisability

This thesis studies have been performed with the use of both quantitative and qualitative methods. The concepts reliability and validity originate in positivist perspective and cannot easily be adopted in the social sciences (see e.g. Bryman, 2008; Golafshani, 2003; Kvale, 1995; Lincoln & Guba, 1986; Winter, 2000). The most common definition of validity, according to Kvale (1995), is to question if we really measure what we intend to measure. In that sense, qualitative research is then invalid if it does not result in numbers (Kvale, 1995). The validity concept must therefore be given a broader definition, so it can be applicable also in social sciences and lead to valid scientific knowledge (Kvale, 1995). Such a definition does not exist; instead, numerous different definitions of validity are used (see e.g. Winter, 2000). In general, within the social sciences, the concept of validity refers to the credibility or believability of the research, and the concept of reliability refers to the repeatability of the findings. Despite the lack of unanimity among researchers’ relating to the interpretation of these concepts, I find it important to question my own research methods and findings, presented in this thesis, in relation to these concepts.

The validity in the four papers, concerning the actual data gathering, is established by the fact that I as researcher conducted the data collection, performed the video recordings of students’ work and interviewed the students and the teachers. The co-author of paper I also assisted during the first data collection. In paper I, several different ways of collecting data were used to ensure the study’s reliability. A triangulation was done, as interviews, video recordings and written tests were used to gather data, from which the analysis builds upon. The analytical framework that was used had previously been proven by others researchers to be a passable way of analysing the effectiveness of laboratory work, which improves the study’s validity. In paper II, video recordings of five groups of students’ talk during the same laboratory work were analysed and categorised to enhance the study’s reliability. The co-author performed inter-rated reliability test, in dividing the groups recordings into sequences with the same activity and thereafter into episodes based on talk-type. A third external researcher coded a sample of 15 episodes, based on communication, which resulted in 87% overall agreement. The use of pre-defined categories, by the other researcher, for analysing both communication and style of the laboratory work, improved the validity of the research.

In paper III, the analysis resulted in several identified specific moves in four categories. To strengthen reliability, concerning the interpretation and existence
of these moves, students’ communication in three additional groups were analysed and coded for moves by the authors individually. These tests resulted in 83% overall agreement, with respect to identified moves. In paper III, the use and development of previous proven successful analytical approaches increases the credibility of presented results. The combination of using existing, and searching for new, moves to answer the research questions strengthens the study’s validity. The outcomes of the study are also generalisable, in the sense that the analytical framework has proven to be a fruitful way of analysing students’ interaction. The same framework with the four guiding analytical questions can most likely be applied in many different contexts of group conversations. However, the identified moves in paper III are linked to a specific physics laboratory context and cannot be presumed to apply in other settings. The identified moves can most likely be expected to differ depending on what type of laboratory work is investigated.

The analytical framework created and presented in paper III, was used in paper IV, to analyse students’ interaction during their planning phase of an open physics inquiry. The validity of the study is also related here to the fact that the analytical tool used had previously undergone and been accepted in peer reviewed process. The study was presented at several seminars whereupon external researchers’ comments and suggestions helped to improve the analysis and contribute to its validity. Furthermore, two groups of researchers examined a transcribed excerpt of students’ conversation independently of each other, based on the given analytical framework. A joint discussion afterwards showed a consistent view and in conformity with our own analysis. These discussions increased the study’s reliability and erased my own concerns that the interpretations of students’ talk were mine alone, although guided by a validated analytical framework.

The general problem with qualitative research, as mentioned earlier, lies in its limited generalisability. This is especially true for the results presented in paper IV. It is not possible to make generalisations based upon one groups’ conversation. The fact that a student’s view of physics and laboratory work differs within a specific class, as well as from other students’, in other schools, is implicit. To make broad generalisations upon the findings would thus be presumptuous. However, it is also important to bear in mind that the study presented in paper IV was conducted at a typical municipal Swedish upper secondary school. It is therefore most plausible that the students’ way of reasoning and interacting is not an isolated occurrence.
A fine grained analysis, such as individuals' interaction, is at the heart of qualitative research, and has the ability to explore processes that go far beyond what any quantitative study could comprehend. The results from sound qualitative research thus becomes a strong voice, with a frequency of its own, which can have remarkable impact on our society.
Summary of the thesis’ papers

In this chapter, a summary of the thesis papers and its main findings are presented.

Paper I

The Effectiveness of Laboratory Work in Physics – A Case Study at Upper Secondary School in Sweden

In this paper, students’ views and experiences of a traditional physics laboratory was the centre of research. The data presented in this first paper in a series of four, build upon the first data collection made during this PhD project. The aim at that early stage of the project was to follow a class of students at upper secondary school level and its physics teacher over a period of three years. The overarching aim was to perform a longitudinal study about the role of laboratory work in physics for both students and teacher. The ambition was to study the impact of implementing different forms of laboratory work, from closed to more open-ended inquiry-based labs. A teacher and 19 students attending their first year at a Swedish science programme took part in the project. The case study presented in paper I stems from this data collection and was an intervention in the sense that we asked the teacher to plan and implement a closed physics investigation for this first data collection. The teacher decided upon the physics content and the outline of the worksheet. The class had just recently begun working with the concept uniform motion. In a lesson prior to the exercise, the teacher introduced concepts such as distance velocity and speed by letting a student try to walk according to a distance time graph in front of the class. The teacher also quickly showed students how a motion detector connected to a computer can be used to record motion in real time. As a continuation of this lesson, the teacher chose to design a similar laboratory work exercise, where all students could further explore distance-time graphs by using the computer-based equipment. The teacher divided the students into six groups. Thereafter, the teacher was interviewed before the laboratory work started. All groups’ laboratory work was video-recorded. Each group of students was interviewed one week after the exercise. One laboratory report for each group was collected for further analysis. Two months later, the students were asked to answer an additional paper and pencil test, consisting of questions of the same character as presented on the worksheet during the laboratory work. The purpose with the study was to analyse the meaning of effectiveness of a laboratory activity, in relation to students’ learning and experiences. The video recordings together with the written assignments were
analysed by using the model introduced by Tiberghien, Veillard, Le Maréchal, Buty and Millar (2001) to investigate the effectiveness of the laboratory work. During the interview, the teacher expressed that the purpose with the exercise was to give students better understanding of distance-time graphs, by using computer-based equipment. The teacher also anticipated that students should consider the meaning of concepts such as distance and positive versus negative position. The purpose with the laboratory task according to the written worksheet was more extensive but entirely of a practical character and related merely to what students should do. They were supposed to analyse the motion as they walked in front of the motion detector, make hypothesis, draw sketches and test how both the position and the velocity changed as a function of time. Under the heading purpose, students were also asked to reflect on the meaning of positive and negative velocity and the meaning of the concept speed. The purpose of the exercise, expressed by the teacher to the students, was that they should learn to manage the computer equipment and the software. The next step in the analysis was to study what the teacher wanted students to do. During the introduction, the teacher emphasised how students should set up the equipment and that they could glance through the first part of the worksheet, relating to the purpose and thereafter concentrate on the second part, containing thorough practical instructions of what to do. The teacher did not at this time mention anything about how they should interpret the graphs. What students were expected to learn about concepts like distance, position, velocity, speed or acceleration were not discussed during the introduction. The instruction contained explicit information concerning what students should do but did not mention anything about how it should be done.

All the groups started the laboratory work by focusing on accomplishing the introductory tasks, where they were supposed to walk in front of the detector to match position-time graphs. Discussions between the students arose at several occasions when their graph did not match the original graph well enough. The students adapted a trial and error approach, where they repeated the exercise until they where satisfied with the result.

During the interviews one week after the activity, students were once again given the same graphs and asked to interpret the diagram as a motion. At this moment, the students had no problems describing the motions and used physics concepts such as velocity, constant velocity and related the velocity to the incline of the position-time graph. Still, the students had difficulties to describe what they thought the teacher expected them to learn from the laboratory work.
Based on the analysis of the video recordings, it becomes clear that students accomplished what the teacher wanted them to do during the actual exercise. The following interviews and result from the written test also show that a majority of the students gained knowledge from the exercise, concerning how to interpret different types of kinematic graphs. The test also indicated that students developed a deeper understanding of physics concepts such as velocity and acceleration. Based on Tiberghien et al.'s (2001) model, the analysis shows that the implemented laboratory work was effective at both level 1 and level 2. A richer analysis of the laboratory tasks, however, gives a more complex picture. Several of the students expressed during the interview that they did not think they learned anything from the exercise.

The analysis shows how the teacher expresses three different purposes with the laboratory task. In the purpose portrayed to the students by the teacher, the practicing and managing of the computer equipment was accentuated. This clearly had high impact and permuted students’ way of taking on the given task. What the teacher expresses and mediates apparently influences students to a high extent. The conclusion based on this case study is that the effectiveness of the physics laboratory work, seen from a teacher perspective, depends on several different factors and does not just depend on what students learn in relation to the teacher’s intentions. One major factor that needs to be comprehended when planning the exercise is the level of challenge offered, in relation to students’ existing knowledge.
In paper II, students’ communication during the physics laboratory work was in focus. The aim with the study was to contribute to the discussions about the effectiveness of laboratory work, by studying if and how students’ communication were affected by the design of the laboratory work. Twenty students attending their first year at an upper secondary science programme, were divided into five groups. The students were video-recorded while performing physics laboratory work with the theme uniformly accelerated motion. The laboratory assignment consisted of four different workstations that students were asked to work through during the time of one and a half hours. The teacher had not, prior to the lesson, been given any instructions or recommendations on how to design the actual laboratory work. The research design can therefore be considered as being flexible. In this situation, we wanted to unconditionally study the implementation of an ordinary physics laboratory work at a Swedish upper secondary school. Immediately during the actual data collection, a difference in students’ communication was noticed. The groups’ way of communicating seemed to change with the given task at the different workstations. Each one of the four stations was analysed quantitatively and compared with respect to what types of activities and communication it generated. The classification scheme presented by Domin (1999) was used to identify and categorise the various workstations. The three indicators: Approach, Outcome and Procedure were searched for to identify the style for each of the four workstations. The analysis resulted in that two workstations were identified as Expository, one as Problem-based and one as Discovery style of laboratory work. Each workstation was then analysed one group at a time, with respect to what activities students were engaged in and what type of communication was generated. Five activities were identified based on iterative viewings of the video recordings: Planning, Preparing equipment, Collecting data, Processing data and Analysis of results. These activities were found in different extents, depending on style of laboratory work. The three different talk types presented by Mercer (1995), that is, Disputational-, Exploratory- and Cumulative talk, were used as an analytical tool to analyse students’ communication. The results showed that a majority of the talk was cumulative. Students were engaged in exploratory talk for little more than 25% of the total time. Disputational talk occurred only on a few occasions. The two stations categorised as expository type generated over
80% of cumulative talk. Students used the most exploratory talk during the workstation categorised as problem-based, followed by the discovery-based workstation. Close to two-thirds of students’ communication was coded as cumulative talk at these two workstations (see Figure 5). In the two workstations coded as expository, the teacher gave students thorough instructions concerning what and how they should proceed with the given task. As a consequence, students used very little time to plan and organise their work at the expository workstations. During the introduction to both the discovery and the problem-based workstations, the teacher emphasised more what students should achieve but did not mention anything about how they should proceed to solve the task at hand. The result shows that the specific design of laboratory work has significant impact on how students communicate with each other.

The analysis shows that the four different workstations offer students similar activities but vary in the extent to which these activities are taking place (see Figure 5). At the two expository stations, students used a majority of the time to collect data and process data; no time was used to plan the work. At the
discovery-based station, students used most of the time to analyse the implication of gathered information. The outcomes from the analysis denote that the activities promote the three talk types to different extents. The activities preparing equipment and collecting data created solitary talk of cumulative character, whilst activities such as planning, processing data and analysis of results foster talk of a more exploratory character. The results from this study highlight the importance of teachers being aware of how different forms of laboratory work shape students’ way of communicating, and especially how different types of activities can be planned to create opportunities and encourage students to discuss physics.
Paper III

The relation between students’ communicative moves during laboratory work in physics and outcomes of their actions

Paper III can be considered as an independent continuation of paper II. The same data material was revisited in order to investigate more deeply the complex sequences of students’ communication during their laboratory work in physics. Throughout the more quantitative analysis of students’ communication in paper II, a need for complementary qualitative analysis gradually emerged. We were interested in examining in more detail what Mercer’s three different types of talk had to offer students in a physics laboratory context. We therefore started to explore the relation between the interaction and content of students’ communication with the purpose of finding new knowledge for informing teachers in their choice of instruction. To find a link between how students communicate and what students communicate about during laboratory work in physics is useful, from both a theoretical and a pedagogical perspective. Discourse analysis has in the past been shown to be a fruitful approach to analyse how students interact on both a linguistic and cognitive level. In this study, the discourse analysis was complemented to also comprehend what students were discussing in terms of content at linguistic and cognitive level. Excerpts from the transcription of one group’s conversations were initially chosen for a qualitative analysis. The analysis comprised how the group of students communicated in a discourse that was influenced by the character of the task and the materiel and equipment available for the students. During the laboratory work, students interacted at several levels simultaneously. The steps students took in such an interaction process, and steps in relation to the actual content, were therefore of interest to explore the actual situation at hand. An analytical framework, based on the work of Barnes and Todd (1995) and Mercer (1995), was developed to not only address the discursive moves made during the exploratory talk, but also to comprehend moves at both linguistic and cognitive level for cumulative and disputational talk. The framework was designed as a four-fold matrix (see Table 5) to structure the analysis in terms of interaction and content-based on the two levels, namely, linguistic and cognition separately. Three main categories of moves: Action Moves, Content moves and Purposive moves, were added to Barnes and Todd’s (1995) already existing Discursive moves for exploratory talk at linguistic level. Four main questions were used to structure the analytical processes: (1) How do they speak to each other? (2) What content is in focus and what topics are discussed? (3) How do the students act and
make progress in the task? and (4) What student purposes do the talk-sequence express?

Table 5: Principle for discourse analysis (Andersson & Enghag, 2017)

<table>
<thead>
<tr>
<th>Linguistic level</th>
<th>Interaction (HOW?)</th>
<th>Content (WHAT?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talk as moves in the dialogue and in the content</td>
<td><strong>Discursive Moves:</strong> How do students speak to each other?</td>
<td><strong>Content Moves:</strong> What content is in focus and what topics are discussed?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cognitive level</th>
<th>Action moves: How do students act when they make progress in the task?</th>
<th>Purposive moves: What student purposes do the talk-sequence express?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talk as actions and thoughts</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Repeated and careful studies of the transcripts resulted in several identified moves, in each of the three types of communications (see Table 6). The different moves identified at a linguistic and cognitive level show how students interact and what underlying purposes they have during the conversation.

As a theoretical contribution, communicative moves during laboratory work in physics has shown to be a successful way to empirically identify how different types of laboratory work activities have different potential strengths for learning outcomes. In the cumulative talks, the purposive moves show how students try to progress with the work, while the purposive moves in the exploratory talks are more individual and intellectually oriented. Students’ purposes in exploratory talks go beyond solving the given task as they strive to expand their conceptual understanding and link to existing knowledge. The analysis shows how easily a conversation that starts in exploratory manner can also turn into disputational talk. In the disputational talks, students’ main purpose becomes to defend their own view instead of truly considering the validity of other students’ explanations. The moves act like waypoints in students’ conversations, from where a new heading is taken, with a new content and new purposes.

As for a pedagogical instrument, the analytical framework can be a valuable tool for physics teachers in the evaluation of their own practice. By identifying content and interaction during activities based on the four questions, teachers can evaluate how well an activity meets the intended learning outcomes.
Table 6: Moves for interaction and content found in the three episodes. Suggested model for empirical analyses of talk during laboratory work.

<table>
<thead>
<tr>
<th>Talk types</th>
<th>Interaction</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disputational talk</td>
<td>Cumulative talk</td>
</tr>
<tr>
<td><strong>Linguistic level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discursive moves:</td>
<td>How do they speak to each other?</td>
<td>Content Moves:</td>
</tr>
<tr>
<td>Action moves:</td>
<td>How do the students act and make progress in the task?</td>
<td>Purposive Moves:</td>
</tr>
</tbody>
</table>

With the help of the analytical framework, modules of laboratory work can be designed to more effectively accommodate specific purposes. The structure of the presented framework is static, in terms of the differentiation between how and what students talk about but should be considered dynamic, in terms of the identified moves under the four main categories.
Paper IV

Open Inquiry-Based Learning in Physics – Students’ Communicative Moves Under Scrutiny

In paper III, a new approach of analysing students’ talk was presented, in terms of interaction and content. A recommendation for further research that arose during that work was to use the analytical framework and follow individual students in their group conversations during the laboratory work. Such an analytical approach could further clarify what content and purposive moves students take and to what extent these purposive moves are fulfilled.

Laboratory work designed as open inquiry occurs more rarely in physics at upper secondary school level than at elementary levels. Still, the Swedish physics curriculum at upper secondary level denotes the importance of students being given opportunities to explore physics with respect to their own references. With this in mind, one of the teachers involved in the project was asked to design an open inquiry-based laboratory work. At the time of the data collection, the design of the study was flexible. We wanted to unconditionally observe how a teacher structured an open physics inquiry and how the students interacted in such a situation, where students could investigate their own areas of interest. The project was documented through video recordings of the teacher’s introduction, students’ planning phase, students’ collecting of data and the different groups’ presentations of their projects. The teacher was interviewed prior to the project starting. Afterwards, both the teacher and the different groups of students were interviewed.

The study presented in paper IV departs from this data, with special attention to the students’ planning phase. Through repeated viewings of the different groups’ discussions, it became clear that during the actual planning phase, students’ different views of laboratory work were brought to the surface, to be expressed and negotiated in a way that did not occur anywhere else during this project. With the aim to explore what choices and on what grounds students made their decisions when given the opportunity to design and execute their own physics laboratory work, a demarcation was therefore made in this study, mainly in the planning phase.

One group was chosen for the fine-grained discourse analysis, due to the fact that the progression of individual students, as well as the group of students, was of special interest, to be followed more closely. It is noteworthy that the students’ communication in the different groups had a similar pattern, where the discussions shifted back and forth between the inquiry, and more general discussions about physics and environmental issues. The choice of group, for a
The video recordings of students’ planning were divided into 30 episodes, based on students’ topic of conversation. Each episode was thereafter coded for type of talk students were engaged in at that moment of time. The analysis reinforces the result from paper 2, that is, activities such as planning generate large amount of exploratory talks among students. The transcribed excerpts from the different episodes were then object of scrutiny, as a thorough discourse analysis was undertaken, using the four-fold matrix to structure the process. Three excerpts were selected and presented in paper IV to exemplify the analytical process and to show the progression of students’ conversation. From the beginning of students’ discussions, the analysis shows how students struggle to break down their different areas of interest into something they can investigate further. Apparently, they initially felt uncomfortable in the situation, where they had to be more active and in charge of the situation than otherwise. In research, a group of students is commonly regarded as a unit. This study highlights how a group of students’ variety of thoughts and ideas are in the centre of attention. Different levels of understanding, interests and knowledge are to be addressed and taken into consideration. The analytical framework accentuates how these different ideas and thoughts are valued and merged into something that everyone in the end agrees upon. Students really struggle to find a way to transform their listed areas of interest into a question that can be investigated. Diverse views of what constitutes actual inquiry emerge from students’ conversations. A demonstration, a systematic investigation and questions were some of the suggested methods to accomplish the inquiry. A contention that students frequently returned to in their discussions was that a physics laboratory investigation is something that is solely connected to a physics discourse, taught in a classroom. The actual laboratory work here became a hurdle for students to concur instead of a valuable instrument that students could use to structure their inquiry. Students’ focus gradually shifts during this planning sequence, going from their areas of interest to instead delving into finding something that was doable and solving the given task. A conclusion that can be drawn based on the study is the importance of physics teachers structuring and planning for a clear progression in the way students use laboratory work as means to acquire new knowledge. To acquire knowledge about, and understand the value of using an investigative approach is equally important as acquiring knowledge in the physics content. Could it be that such discussions get lost in the pursuit of understanding the extensive core physics content?
Discussion

The investigation lies at the heart of science. Therefore it feels natural and essential to also incorporate laboratory work as a teaching and learning method in science education. Most researchers and educators in the field of science education agree in that respect. How to effectively take advantage of, and in the best way possible, implement laboratory work is thus still in focus of debate and research. So how can the physics laboratory work at upper secondary be structured and implemented to enhance students’ learning in and about physics? To answer this, the overarching research question in this thesis, I will further elaborate on the results from the four papers in the discussion section.

Effectiveness of laboratory work

In paper I, an attempt was made to explore the effectiveness of laboratory work as a method of learning and understanding physics. The outcome of the analysis indicated that the performed laboratory activity was effective, in the sense that the students both did and learned what the teacher intended. Moreover, the study showed that a specific laboratory assignment can be effective, based on Millar et al.’s (2002) model, contrary to the students’ own experiences. However, the design of study did not establish in detail students’ existing knowledge and understanding about the kinematic concepts, prior to the study. Effectiveness is commonly referred to as the change of a quantity with respect to time. Effectiveness in paper I instead relates to if students actually do what the teacher intended them to do and if they learned what the teacher intended them to learn (Andrée Tiberghien et al., 2001). It is here the inherent complexity of laboratory work comes into play. What students are about to learn in a physics course at upper secondary school incorporates not only the core physics content, but also the nature of physics and the role of physics in the development of society. Hodson (2014) expresses that there are four basic learning goals to draw careful distinctions among: learning science, learning about science, doing science and learning to address socio-scientific issues. All of these learning goals are accommodated within the context of practising laboratory work. The effectiveness of one isolated physics laboratory exercise therefore depends not only on what the teacher wants the students to do and learn, but also how the particular design of the exercise meets such criteria. Moreover, the implementation of a special laboratory exercise can also address several different learning goals.
Another factor that was not addressed in paper I was the activity’s efficiency. With efficiency, I denote the actual quality of the task, that is, how well students succeeded in relation to how demanding the activity was at a cognitive level. To what extent did the activity challenge students’ existing knowledge? To what extent did students need to engage in exploratory talks to understand more deeply the meaning of the actual physics concepts? The analysis in paper I showed that students indeed talked about the concepts they were supposed to investigate, but the quality of those discussions were never under the lens for scrutiny. After studying students’ communication and its relation to the design of the laboratory work in paper II, it becomes clear that if the effectiveness of a specific laboratory work is to be evaluated, then it is necessary to incorporate the efficiency of both the actual task and students’ communication in the analysis. If a physics teacher is to design and use laboratory work effectively, then the level of challenge the activity offers the students becomes a major factor for how students experience the task. In that respect, the expository style of laboratory work is not an appropriate approach. A design where students are given thorough instructions about what to do and how to do it limits the offered linguistic and cognitive challenge. My opinion is that a structured design of such a character can still be productive in some scenarios, such as where students are expected to learn how to use equipment, or learn how to carry out a systematic investigation. The teachers’ intention with the activity is therefore important when designing the task. How the teacher declares, not only what students are supposed to do, but also what they are supposed to learn from the activity becomes fundamental. If students are aware of what they are expected to learn by doing the laboratory work, the probability that students experience the activity as interesting and worthwhile increases (Jacobsen, 2010).

**Students’ communication**

In paper II, it becomes evident that the design of the physics laboratory work affects students’ communication. This is a factor that needs to be further emphasised in the ongoing debate about the effectiveness of laboratory work. In the analysis of paper II, five groups of students’ communication were analysed based on style of physics laboratory work and the activities the tasks generated. The character of students’ communication correlated with the activity that students were engaged in. It is important to remember that the study was naturalistic, in the sense that the teacher designed and implemented the laboratory lesson without any requests or demands from others. The concept of effectiveness in paper I also permutes the study presented in paper II, where the cognitive demands of the different tasks, most likely also effect
how students talk. In paper II, two workstations were categorised as expository styles. This type of work seems to accentuate the work process, where students seemingly unaware, prioritise to correctly follow the given instructions. The few conceptual discussions at the expository workstations arose as a last phase of the students’ work. At the other workstations of a more open character, students were, to a higher extent, engaged in exploratory talks. With an increased degree of openness, where students have to take more responsibility, the challenge also increases. The cognitive load of the task seems to impact students’ communication. A laboratory task where students need to spend a considerably amount of the given time, to activities such as planning, processing data and analysis of results, fosters exploratory talks. So the efficiency of students’ communication seemingly corresponds to how challenging the laboratory task actually is. If the task is too difficult or too easy for the students, it will most likely have a negative impact on students’ experiences and also on the quality of students’ conversations. The laboratory work must be closely integrated, as a teaching and learning method, in the physics education. If the teacher is well aware of the students’ existing knowledge and can design the laboratory work accordingly, the cognitive challenge is within the zone of a proximal development (Vygotsky, 1978). Many teachers use laboratory work as a means to stimulate and enhance students’ interest in physics. Students in general also seem to appreciate it as a special element in the science education, different from ordinary theory lessons. However, it is also important to teach students how to correctly use a scientific investigative process to answer posed questions. If students master the investigative approach, they can with confidence use the results to assimilate new understanding and knowledge, as well as argument for an opinion. The right design of the laboratory task that addresses what students really need to practise or experience must be the first step to meet the criteria of effectiveness. The next step is that both students and teachers be well aware of the affordances communicating science with others can have on the individuals learning. Working in small groups therefore becomes valuable time for students. By listening to how other peers understand and reason, their ideas and thoughts are ideally compared and questioned. New insight, based on observations made as well others’ expressed thoughts, can lead to new understanding or reinforcing of existing knowledge.

In paper III, the purpose was to examine in-depth what different types of communication has to offer students at both a linguistic and cognitive level. The result strengthens the view that exploratory talk possesses the most valuable way of talking, from an educational perspective. To understand what
different types of talk have to offer, observing students in a laboratory context is valuable for researchers and teachers. The framework presented in paper III further clarifies the differences between the three talk types through the identification of specific moves for interaction and content, at both a linguistic and cognitive level. Moreover, the four guiding questions can further be used to analyse individual students’ communication during work in small groups: How do the students speak to each other? What are they talking about? How do the students act when making progress? What purposes do the students express? Research about students’ communication during different types of laboratory work is needed to understand how students make choices and to what extent students’ expressed purposes are fulfilled.

The physics curriculum

Since the Swedish upper secondary school system was introduced in the beginning of the 70s, the syllabus has undergone several reforms up to the latest reform that was launched in 2011. With these changes of reforms over time, the physics laboratory work has been given a more prominent role as a teaching and learning method in the curriculum. It is stated that students should be given opportunities to develop their ability to seek answers to questions, plan, implement, manage equipment, interpret and present results. Students should also be able to use their physics knowledge to communicate, argument and present conclusions (Swedish School Agency, 2011). There has been a clear change in the physics curriculum, going from emphasising the core physics content from a teacher perspective to acquiring knowledge in physics as well as about physics, from a student perspective. How the above-mentioned abilities, together with the central content described in the syllabus, should be realised is for the practicing physics teacher to decide. The laboratory work’s role here becomes an important factor from a teaching and learning perspective, as it can naturally offer students opportunities to practise these abilities while the central content is in focus. The design of the laboratory work here becomes an essential element to create such a learning environment.

The general positive attitude amongst teachers, towards using laboratory work as an integrated element of the physics education, is easy to understand. Its comprehensive versatility is a major factor contributing to its usefulness. However, I believe that there is a risk that this versatility means an indistinctness of teachers’ objective with the laboratory work. Today, many science programmes at Swedish upper secondary schools have fixed scheduled positions, where students are expected to engage in science laboratory work. An
advantage with such a structure is that students are given opportunities to work practically. At the same time, it becomes a challenge for teachers to plan and design the laboratory activities so it addresses specific areas in physics that makes students move forward in their physics understanding. Otherwise, there is a risk that the laboratory activities become yet another isolated event in physics. Teachers must have knowledge concerning what different aims the laboratory work can address. It is equally important then to ask how the laboratory work can be designed to efficiently address those aims? Students do not automatically learn how to use the scientific investigative approach just by doing laboratory work. Students also need to be trained in how to do a scientific investigation, as well as be informed about the affordances of cooperative learning. In that sense, the design of the laboratory work can set limits for students learning.

Hence, is open inquiry an effective approach to learning science?

As mentioned earlier, the debate about using open inquiry in science education is clearly differentiated (Hmelo-Silver et al., 2007; Kirschner et al., 2006). It is unquestionable that introducing open inquiry in the physics classroom is a time consuming pedagogical challenge for any teacher. The outcomes of the different group investigations in paper IV were rather poor in relation to the time students spent on designing, planning and collecting data. Much of the results, in terms of the new core physics content students comprehended could easily have been demonstrated or taught to the students in a fraction of the projects total time. Nevertheless, I firmly believe that students regularly need to encounter this type of laboratory work at upper secondary school as it contributes to and challenges students’ existing view of the nature of physics. The analysis in paper IV strengthens this assertion, as it shows how students struggle to transform their ideas into an investigation. The students in paper IV initially found themselves in a new uncomfortable situation, where they, themselves, were expected to design their own investigation. This situation stresses that students also need to be taught how to conduct an inquiry. There is a risk that physics laboratory work designed to teach students about the scientific investigate approach disappears in a mixture of other aims relating to the core physics content. A possible way to address this problem could be to develop a progression plan specifically for the laboratory work. Physics teachers generally follow a structured plan on how to gradually build students’ physics content knowledge, where the laboratory work is used as a teaching and learning method. Based on the results in paper IV, I believe that the labwork at upper secondary school could be gained with a similar structure, where teachers intentionally and gradually let students learn about laboratory work.
The physics content knowledge is the dominant element in physics education at upper secondary school. Students need to acquire a profound understanding of physics to be well prepared for society and further studies at universities. This also includes understanding how the investigative approach is used to acquire knowledge that is both reliable and valid. The physics curriculum is dense, with respect to the amount of content knowledge students are expected to grasp and understand, after studies in physics at upper secondary school. The timeframe is limited, and different elements in the subject demand more or less attention. This is and will continue to be a challenge for teachers in the future.

So what has happened since Hofstein and Lunetta (1980) wrote their review of the laboratory work in the early 80s? I would say a great deal! Research in science education is still a relatively new field, from which the results gradually have started to move into the classrooms. The standardised test in physics now includes tasks where students have to plan and present an appropriate investigative method to answer a question. Moreover, a practical element in the test is also included, where students perform, analyse and present their results in a report. Highlighting these elements in standardised tests also influences how teachers practise and teach. Teachers in general are curious and eager to develop their practise continuously. In this project, I had the opportunity to work with such teachers, and based on my own experience I strongly believe that research in this field should be done together with practising teachers whenever possible. In that way, the implications of the findings can have a greater impact.

Further research

Students’ communication during laboratory work has proven to be a fruitful way to better understand how different designs of laboratory work influence students’ learning. The value for students to engage in exploratory talk has been emphasised in this work. A next step could be to investigate in more depth the nature of the exploratory talk and how individual students pursue and develop understanding of specific physics concepts through communication, in the context of laboratory work.
References


Learning Physics Through Communication During Laboratory Work

Laboratory work as a teaching and learning method is given prominence in the Swedish physics curriculum for upper secondary school. It is emphasised that students should be given opportunities to develop the ability to search for answers to questions, plan, conduct, interpret and present results. Moreover, students should also be encouraged to use their physics knowledge to communicate, argument and present conclusions. This thesis is based on the belief that physics laboratory work creates a special discourse, where the student becomes the actor and the teacher becomes the organiser and observer. Through analysis of students’ communication, the purpose is to better understand the physics laboratory work’s possibilities as a teaching and learning method. The results show that laboratory work consists of similar activities but differs in amount of time allocated to the different activities. Different types of talk are used for different purposes. An analytical framework has been created to enable deeper investigations of how and what students are talking about at both a linguistic and cognitive level. Moreover, the analysis shows the importance of students acquiring knowledge about physics and understanding the value of using an investigative approach as well as acquiring core content physics knowledge.