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THE LABORATORY WORK STYLE'S INFLUENCE ON STUDENTS' COMMUNICATION

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Abstract. *More knowledge of how the actual design of the laboratory work influence students' communication, is needed to design and implement physics laboratory work lessons. The aim with this quantitative research, conducted at a Swedish upper secondary school, was to explore how the design of the laboratory work affects students' communication. Twenty students divided into five groups participated in this natural case study and were video recorded while performing four practical tasks with the theme uniformly accelerated motion, designed by their teacher. The four workstations were categorised based on three predefined descriptors: outcome, approach and procedure. Students' work at each workstation was coded according to five defined activities: planning, preparing equipment, collecting data, processing data and analysis of results. The activities were thereafter divided into shorter episodes that were coded for three different types of communication: disputational talk, cumulative talk and exploratory talk. The result shows that the amount of exploratory talk students engaged in are influenced by the style of the laboratory work and the character of the activity. Based on these research results, teachers can better accustom the laboratory work to facilitate fruitful physics discussions which endorse students' learning.*
Keywords: *different styles of laboratory work, different types of talk, quantitative analysis of students' communication.*

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Introduction

Studies about laboratory work in science education have, over the last fifteen years, been the subject of a large body of research (for example Abrahams & Millar, 2008; Dillon, 2008; Hofstein & Lunetta, 2004; Jacobsen, 2010). Parallel to this, the number of studies about communication in the science classroom has grown considerably, becoming a research domain of its own (for example, Bennet, Hogarth, Lubben, Campbell & Robinson, 2010; Dawes & Staarman, 2009; Kind, Kind, Hofstein & Wilson, 2011; Mercer, 2010; Oyoo, 2012. Researchers in the field of laboratory work and in the field of communication stress the importance of science teachers eliciting students to communicate about science and giving them opportunities to perform laboratory work. If students' communication is affected by the context of laboratory work, this might have consequences for the efficiency of the lesson, both in aspects of learning outcomes and of new experiences for students.

Terms as practical work, laboratory work and experimental work are often used arbitrary (Hodson, 1988). In this research, the term laboratory work is used to describe any type of scientific teaching and learning activity in which students, working either individually or in small groups, are involved in manipulating and/or observing real objects and materials (Abrahams & Reiss, 2012).

The design of the laboratory work depends on the teacher's purpose with the science lesson. The extensive European report about laboratory work in science education (Séré, Leach, Niedderer, Psillos, Tiberghien, Vicentini, 1998) lists three broad purposes of laboratory work, as expressed by teachers: 1) *Developing students' knowledge of the behaviour of the natural world*, 2) *Learning to do empirical investigations* and 3) *Learning to handle laboratory equipment*. Another argument for the purpose of laboratory work in physics has been to enhance students' ability to link theory to practice (Boud, Dunn, & Hegarty-Hazel, 1986; Lunetta, 1998). It is noteworthy that none of the aforementioned purposes of laboratory work concerns giving students opportunities to talk physics with each other. Tiberghien, Veillard, Le Maréchal, Buty and Millar (2001) mean that the main purpose of all laboratory work should be to create links between the domain of observables to the domain of ideas. Students should be able to describe what they have done and observed. They should also be able to discuss the practical work and employ the ideas meant to be developed, or be able to use these ideas in a different context (Tiberghien et al., 2001). This might implicate that students need time to talk and discuss.

Abrahams and Millar (2008) do not expressly use the term communication but instead state that science is about the interplay of individual observation and ideas, where practical work plays an important role in helping the student establish links between these two domains. By ideas, Abrahams and Reiss (2012) refer to the process of thinking and talking about objects and materials, using scientific terminology and theoretical entities or constructs, which are not themselves directly observable. Could not student interplay between observations and ideas being enhanced by communication between students?

Scott, Mortimer, and Ametller (2011) argue that link-making is defined by 1) how the learner makes links between existing knowledge and new ideas, but also 2) that learning conceptual scientific knowledge involves recognising how the scientific concepts themselves fit together in an interlinking system (Scott et al., 2011). According to Driver (1989) students come to their science classes with prior conceptions that may differ substantially from the ideas being taught, and these conceptions may be resistant to change. Laboratory work most likely possesses qualifications and can act as a pedagogical tool, facilitating the link-making process and stimulating changes in students' prior conceptual perceptions. This link-making process can occur at two levels and is an indicator of the effectiveness of the laboratory work in terms of doing and learning outcomes (Abrahams & Millar, 2008).

A laboratory task can be effective at the first level from the point of "doing", which means that students do what the teacher intended for them to do. At the second level, a laboratory task can be effective from a "learning" perspective, whereby they learn what the teacher intended for them to learn. Later, if students can, in another situation, discuss and use the knowledge, which the laboratory tasks were meant to develop, the tasks are said to be effective (Tiberghien et al., 2001). Kind et al. (2011) state that the quality of students' argumentation during laboratory work also reflects the quality of their investigations. This view of effectiveness highlights the importance of research concerning student communication during practical work.

Traditionally, practical work in physics is accomplished as small group work, which naturally involves verbal communication among students. Bennett et al., (2010) argue that for small group discussions to be effective, students need to be explicitly taught how to develop arguments and characteristics associated with effective group discussions. Katchevich, Hofstein and Mamlok-Naaman (2013) argue that if students are engaged in activities that provide them with opportunities to develop argumentative skills, they also learn how to conduct a meaningful conversation with peers. Mercer, Dawes and Staarman (2009) stress the importance of teachers ensuring that group activities are well designed to elicit debate and discussion. Activities should not only draw on students' existing knowledge, but also expand that knowledge by introducing and making links to new ideas.

More research concerning the link between students' communication and laboratory work are needed to further unravel and clarify the complexity of laboratory work in physics education. This research contributes with new knowledge within this area by examining how the type of laboratory work in physics influences students' interaction and communication.

Different Styles of Laboratory Work

Discussions about different styles of laboratory work have mostly concerned degrees of freedom, where closed labs have zero or low degrees of freedom compared to more open-ended labs (Herron, 1971; Schwab, 1962). Instead of classifying different styles of laboratory work through degrees of freedom, Domin (1999) uses descriptors such as Outcome, Approach and Procedure to distinguish four different styles of laboratory work, which are labelled as expository, inquiry, discovery and problem-based instruction style. A predetermined outcome implies that both the instructor and the students know the outcome of the work. An undetermined outcome involves investigations where students, and sometimes the teacher, do not know the actual result in advance. The approach can be either deductive or inductive according to Domin (1999). A deductive approach is applied when students use a general principle toward understanding a specific phenomenon. An inductive approach is used when students draw conclusions based on what they have observed. In some cases, the students follow a procedure provided either by the teacher or other learning materials, which dictates what to do and how to do it. If, instead, the students design the procedure, they decide themselves what needs to be done and how to do it. Based on the analysis of the three descriptors, a laboratory exercise can be categorised into one of four different styles, defined as follows.

Expository style. Students are asked to perform laboratory work that verifies scientific facts. These facts are

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introduced prior to the laboratory work in textbooks and during lectures. The teacher usually gives students thorough instructions with regard to both what they are supposed to do and how they are expected to complete the task. The students then follow the teacher's instructions and compare their own results from the laboratory work against the expected outcome. This is the most common style of doing laboratory work (Séré et al., 1998), and is often called a cookbook lab because it requires students to follow a recipe-like instruction (Royuk & Brooks, 2003). The cognitive skills required and developed by such laboratory tasks are far more practical than theoretical in nature (Roth, Mcginn, & Bowen, 1996). One reason for this is that students spend more time determining whether they obtained the correct results than they spend thinking, planning and organizing the experiment (Domin, 1999).

Inquiry style. The teacher gives the students an assignment in which they are asked to investigate certain factors that demonstrate a specific variable or concept. The task should be vague enough so that students have to design their own experiment, including collecting and analysing their own data. The inquiry style is characterised by an undetermined outcome, an inductive approach and a student-generated procedure. This style of doing practical work resembles true scientific investigation, in the sense that the outcome is unknown (Domin,1999). Students' involvement increases when they are responsible for designing and implementing an investigation. The inquiry style therefore requires more time, and makes greater demands on students, teachers, and school facilities.

Discovery style. Without any theoretical introduction, the students are asked to follow a given instruction, telling them what to do and what data to collect. Based on the collected data, the students are expected to draw conclusions. This experience, together with post-lab discussions, gives the students the opportunity to discover and understand the underlying concepts. This style of laboratory work is characterised by a predetermined outcome, an inductive approach and a given procedure. This style is also referred to as guided-inquiry. According to Domin (1999) this form of learning has been heavily criticised. One reason is that when one student in a group discovers the principle of interest, the others will most likely be given the information.

Problem-based style. Students are given a problem to solve. They are expected to do so by applying theories from readings and prior lectures. By solving the problem, students are expected to gain a better understanding of the underlying concepts. This style of laboratory work is characterised by predetermined outcome, a deductive approach and a student-generated procedure. Using a problem-based style requires that students have good conceptual understanding and can use their knowledge to solve problems and answer questions. In this case students must create their own procedures to solve the problem, and Domin (1999) means that emphasis is placed on developing testable hypotheses, rather than obtaining correct results.

Domin's three descriptors were used in this research to identify and distinguish the different styles of laboratory work students are working with during a 90-minute physics lesson. It is important to stress that goal with this research was not primarily to make comparisons between Domin's different styles of laboratory work in turns of learning outcomes. Instead, the main objective was to investigate whether and how different styles of laboratory work promote different types of communication, where language is an important link to the construction of knowledge.

Different Styles of Communication

Spoken language is one of several communicative modes, probably the most important (Jewitt, Kress, Ogborn, & Tsatsarelis, 2010; Mercer, 2010). The conversation students make in small groups during practical work captures the communication that occurs when students construct meaning from new experiences and new knowledge afforded by tasks and activities. For participants to gain entry into a critical discussion, they must first agree to pursue an issue or topic on which they have divergent opinions. Thus, an initial requirement is that participants produce arguments articulating divergent perspectives, which can then lead to agreement on an issue or topic to discuss (van Eemeren & Grootendorst, 1987).

The different types of communication can be seen as the discourse that reveals both different forms of activities students are engaged in, and on a deeper level, their intentions and interactions to make meaning. Mercer and Littleton (2007) elaborate how collective construction of knowledge is achieved, and how engagement in dialogue shapes students' educational progress and intellectual development. Vygotsky's sociocultural theory and Bahktin's dialogism form the foundation to explain these ideas (Bakhtin, 1986; Vygotsky, 1978). Lemke (1990) expressed the importance of talk in a physics classroom in a way that has become cited frequently:

> Learning science means learning to talk science. It also means learning to use this specialized conceptual language in reading and writing, in reasoning and problem solving, and in guiding practical action in the laboratory and in daily life. It means learning to communicate in the language of science and act as a member of the community of people who do so (Lemke, 1990 ,p.1).

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 characterised by disagreement and exchanges of assertions and counter-assertions and is characterized by a debate. The relationship is competitive, where the defence of individuals' ideas are prioritized over consideration of others' explanations.

Cumulative talk is built up by repetitions, confirmations and elaborations. Like exploratory talk, it allows for construction of common knowledge by accumulation. In the cumulative discourse the speakers build positively but uncritically on what others have said. Information and ideas are shared in the process of constructing knowledge, but without being challenged.

Exploratory talk is seen as the valuable type of conversation in which statements and suggestions are offered for joint consideration, and the speakers show critical and constructive engagement in each other's ideas. Alternate viewpoints are often suggested and the quest for knowledge is more viable through such reasoning and talk.

A further and more detailed description of these talk types is presented by Andersson & Enghag (2017), who performed a discourse analysis of students' talk during laboratory work, to find qualitative differences among the talk-types, at both a linguistic and cognitive level. The three types of talk were in this research used to quantitatively analyse students' communication during their laboratory work.

Purpose and Research Questions

The aim of this research was to examine students' communication during different styles of laboratory work in physics. The purpose was to better understand the relation between the style of the laboratory work, the activities it generates and talk-types in use by answering the following questions:

1. How does the style of the laboratory work relate with the talk-type between students?

2. What activities does the laboratory work generate and how do the activities relate with the talk-types between students?

More research is needed to better understand how the physics laboratory work can be improved to enhance students' learning. Searching for a possible relation between the design of the laboratory work and the quality of students' communication is therefore important. Such information provides knowledge about how student development of competencies during laboratory work could be facilitated in a more systematic way.

Methodology of Research

Investigating Four Laboratory Workstations by Analysis of Styles, Activities and Talk-Types

A quantitative approach was used to find answers to the research questions, where descriptive statistical analysis was used to discover similarities and differences in students' way of communicating during their work at the four different workstations. Statistical comparisons tests were then conducted to establish if signs of occurring differences in fact were statistical significant.

The style of the laboratory work was in a first step identified by analysing the worksheets' content, with particular regard to how the tasks and questions were formulated, by searching for descriptors as outcome, approach and procedure. Thereafter in a second step, the recorded films of students' work were studied, in order to inductively identify and define different activities which students were engaged in during the process of laboratory work. Finally, the relation between both laboratory styles and activities in relation to talk-types was established. Five hours of student's communication during this laboratory lesson, were analysed in this research.

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Participants, Learning Environment and Procedure

The research was conducted at a Swedish upper secondary municipal school with a total of 600 students. The school's natural science and social science programs dominate the curriculum, but more practically oriented programs also exist. The students who participated in this research were 16 to 17 years old and attended their first physics course as a part of a science program. The students were informed about ethical guidelines from the Swedish Research Council, and had given their written permission to take part in the studies. The teacher divided the class of 20 students into five groups of four. The teacher did not take students' individual abilities into consideration when constructing the groups, but instead divided them according to the class participant list. At this school, laboratory work in physics was scheduled once every two weeks. During laboratory work lessons, the entire class was divided in half. One half started by doing experiments in physics and the other half in chemistry. After 90 minutes the two groups switched subjects. At the time of observation, the students had just started working with the topic of uniformly accelerated motion, and had not done any laboratory work in this field prior to this lesson at the upper secondary school. The teacher had planned and prepared a lesson consisting of four different laboratory tasks with the theme *motion*. Choices of laboratory work and preparation of the lessons were done entirely by the teacher himself. No form of intervention was thus undertaken, making this a natural case study. The four different laboratory workstations were placed in separate rooms to enable good audio recording conditions. A camera was positioned in each room to continuously record students' interaction and discussions. When introducing the lesson, the teacher informed the students about the division of groups and handed out a worksheet (see Appendix). Brief methodology instructions were then given to the students at each workstation. The students had 60 minutes in total to their work, 15 minutes at each station. The remaining 30 minutes was used for introduction and closure of the lesson. The data this research builds upon, is part of a more extensive project, concerning the physics laboratory work's role in students' learning at upper secondary level. The laboratory lesson described in this research was thus not designed to consist of four different styles of laboratory work, as defined by Domin (1999). During the recording of students' work at the different workstations, a clear difference in students' way of interacting was noted. Based on this observation we afterwards began to investigate if and how the four workstations differed in its design, and if it could have influenced students' way of talking.

Generalizability, Reliability and Validity

Regarding generalizability, this research does not formulate broad claims, but invites readers of research to make connections between elements of the research and their own experiences. The results from this research are intended to indicate a possible existent of a relation between the style of the laboratory work, the activities and the talk it generates. The work of five different groups, in the analysis referred to as group A, B, C, D and E, with four students in each group was analysed to strengthen the reliability of the study. The co-author performed inter-rater reliability studies, in dividing the groups recordings into sequences with the same activity and thereafter into episodes based on talk types. A third researcher, not involved in the actual analysis, was asked to perform an additional inter-rater reliability test, were 15 episodes was coded for type of communication, which resulted in an 87% overall agreement. The validity of the study is strengthened using predefined analytical instruments as Domin's categorisation scheme to identify different styles of laboratory work and Mercer's approach to distinguish three different types of talk. Statistical comparison tests, such as two-way ANOVA and t-tests were also performed to search for possible significant differences between the styles of the laboratory work, activities and groups of students, in relation to the different types of talk student were engaged in. The total amount of time coded as cumulative talk and exploratory talk, was for each type of laboratory style and group of students summarised and compared, to see if any significant difference existed between the factors. The same approach was used to see if there was any difference between the distribution of the talk-types, with respect to the different activities students were engaged in. More and larger studies with the same approach are though needed to further claim the results generalisations.

Results of Research

Each of the four laboratory workstations were analysed in accordance with the three steps: laboratory styles, activities and talk-types, described in the methods section.

Laboratory Styles

Three of the four laboratory workstations agreed with Domin's descriptors, two as expository style of work and one as discovery. One of the workstations did not fulfil Abraham and Reiss' (2012) criteria for being a laboratory work, in the sense that students did not manipulate and/or observe real objects and materials. Domin's three descriptors could still be found and recognised within the particular workstation, making us categorise it as a problem based style of task. Each one of the workstations will be described in detail below.

Activities

Thorough and repeated studies of the first group's transcribed communication, together with the corresponding computer-based categorisation of video recordings of all the five groups, resulted in five identified activities: Planning, Preparing Equipment, Collecting Data, Processing Data and Analysis of Results. Descriptions of the activities are given in Table 1.

Table 1. Activities (Indicators: Talk and observed actions seen on the video).

Activity	Description
Planning	Students become acquainted with the task and go through what to do and how to do it. Students jointly decide how to carry out a data collection, or discuss what data is needed to solve a given task.
Preparing Equipment	Students set up equipment to collect necessary data.
Collecting Data	Students collect data by doing some sort of measurements or attempts, using available equipment.
Processing Data	Time spent when students process data, given or collected. Derive a mathematical expression, calculate a value, or draw diagrams.
Analysis of Results	Time spent where students answer questions in the worksheet or discuss the meaning and accuracy of the results at different levels, or answer questions in the worksheet.

The video recordings from each group 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 of collecting data and ending 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 specific 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 result meaning.
III. Finally, each episode was coded for the three different types of talk students were engaged in at that moment of time.

Activities and Talk-types for Each Station

The categorisation of the individual five groups work at each station, based on activities and talk types, was then compiled to clustered stacked column charts. The analysis and results that follow are presented separately for each station. A summary of the results is given at the end of this section.

Station 1: The Tape Timer

Description and analysis of the task. The task was to calculate a value of the gravitational acceleration *g*, by using a tape timer to register a 1.5 meter fall of a 1kg weight, and then discuss if and why the value deviates from 9.82 (see Appendix). The students were equipped with a tape timer, a power supply unit, a 1kg weight and a roll of paper strip. Prior to the lesson, the teacher had prepared the equipment by setting up the tape timer and con-

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necting it to a power supply. During the introduction the teacher showed the students how to thread the paper strip in the tape timer and described how to analyse the markings on the paper strip. The teacher thoroughly explained how the students should collect the data and what they were expected to calculate. The outcome was given as the students were told to compare their value to the gravitational acceleration constant. The approach can be considered to be deductive as the students were given a formula to use for calculations. The student followed a given procedure since the teacher initially informed them clearly and step-by-step, on what to do and how to calculate the acceleration. This laboratory work has been categorised as a typical Expository style, based on the three descriptors.

Analysis of students' activities. Four of the groups immediately started by preparing the tape timer. One group started out by briefly talking through what they were supposed to do before preparing for their data collection. Most of the groups made two attempts after which they selected the strip with the clearest dots. The students placed the paper strip on the table, counted fifty dots and measured the displacement. All students appeared to be well aware of the work process and completed the task within the given time frame. All the groups realized that they had to solve the given equation, $y=at^2/2$ for a. All calculations were done individually, but the students used each other to check their algebraic and numerical calculations and finally arrived at the results within the range of 9.4 to 10.2 m/s^2. The groups managed to calculate a value for the acceleration of the falling weight, but one group used considerably more time preparing the equipment and therefore had no time to analyse their end result. The task written in the worksheet was to calculate a value for *g*. The link between the acceleration *a* and the quantity of the gravitational acceleration *g* was a topic of discussion in three of five groups. Also, the unit for acceleration was not clear to all students, and this started discussion in some of the groups.

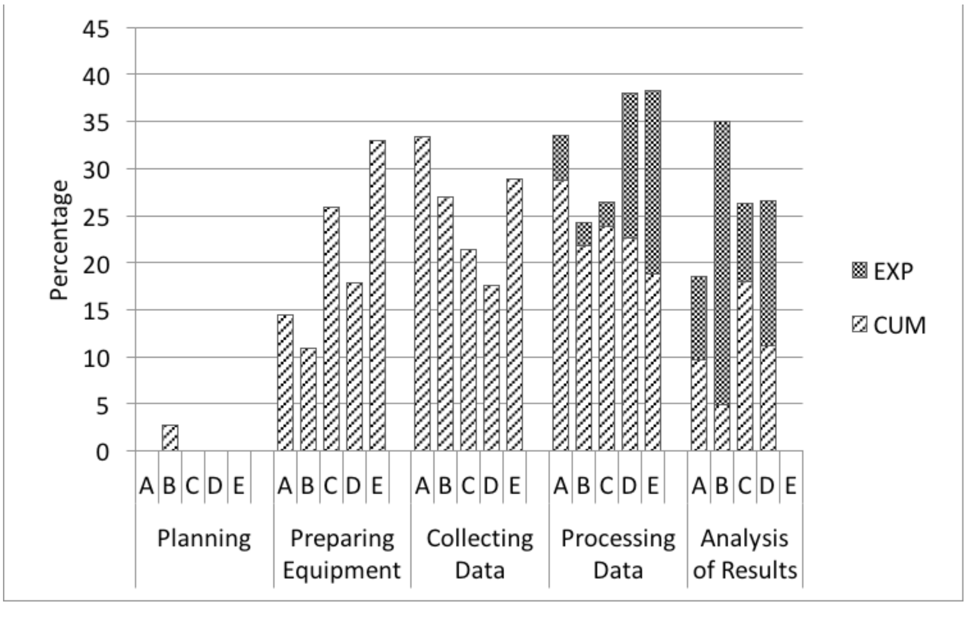

Figure 1: Tape Timer. Individual group activities and talk-types categorised with time as unit of analysis.

During this laboratory work all groups were engaged in four of the five defined activities (see figure 1). Generally, the students seemed to be well aware of the work process and completed the task within the given time frame. The lack of time spent on planning is most likely a consequence of the teacher's thorough introduction. Overall, the linear structure of this laboratory work was evident as the groups started and completed one activity after another. Most groups began by Preparing Equipment, followed by Collecting Data, and Processing Data, and ended their work with Analysis of Results. Overall, students spent the most time on Processing Data, which corresponded to 35% of the time (see figure 2). 26 % of the time was coded as collecting data, while preparing equipment and analysis of results each consumed 21% of the time.

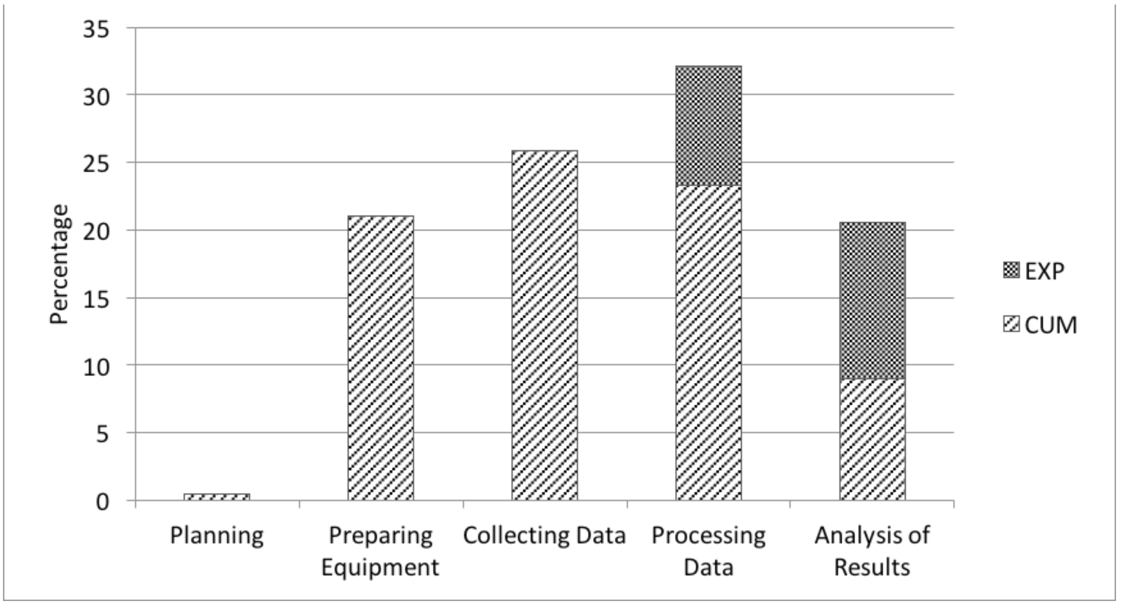

Figure 2: Tape Timer. Summary of activities and talk-types categorised with time as unit of analysis.

Analysis of students' communication. Each of the activities were also quantitatively analysed based on talk-type. 46 of 64 episodes were categorised as cumulative talk, which is equivalent to 80%, with time as unit of analysis. 18 episodes were coded as exploratory talk, corresponding to 20% of the total time (see figure 2). The common characteristic for these exploratory talk episodes was that the students discussed how to solve the equation $y=at^2/2$ for *a,* and questioned parts of their results. The exploratory talks solely occurred during the activities *Processing Data* and *Analysis of results* (see figure 2). In the 46 episodes coded as cumulative talk the students were working purposefully, following the instruction given by the teacher.

Station 2: The Position-Time Graph

Description and analysis of the task. The worksheet consisted of a story about a person named Karin who was walking around on her farm performing different chores. The students' task was to describe and represent sequences of these events in a position-time graph (see Appendix). The instruction contained four parts, one of which was formulated as a question. None of the parts required any sort of calculations. Rather, the students were asked to draw, describe and indirectly analyse the limitations of the position-time diagrams. The main task was to describe and represent Karin's motion by drawing a position-time graph. The approach presented in the instruction was defined as deductive, since students had to use their conceptual knowledge about displacement and velocity as vectors. The procedure in this activity was categorised as student-generated. The worksheet was informative but did not give any guidance as to how to draw the graph. The descriptor outcome was categorised as undetermined, since the students created a graph based on their interpretations. This activity could not be classified directly into one of Domin's four styles of laboratory work. But the style that closest matched the structure of this task was the problem-based type, which requires students to use and reflect on their knowledge to solve a problem.

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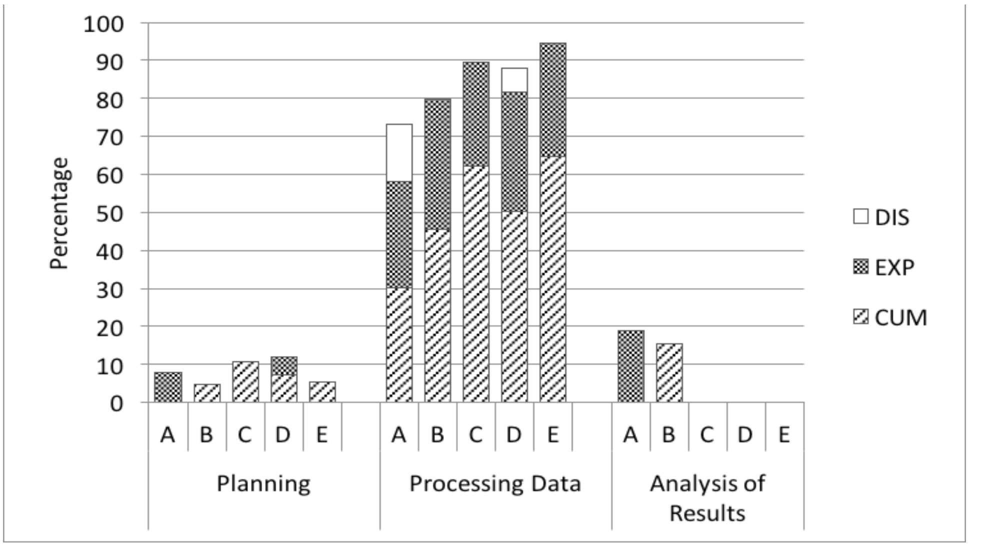

Figure 3: Position-Time Graph. Individual group activities and talk-types categorised with time as unit of analysis.

Analysis of students' activities. This task differed from the others in that students did not use any equipment. All five groups began by reading the instruction and then talking about how to proceed with the task. In these first episodes two groups independently discussed which quantities they did and did not know. They both arrived at the conclusion that they knew displacement but not time, and that they would have to decide Karin's velocity themselves. Other groups discussed how much time the person in the story used for the different chores; these activities were coded as Planning and corresponded to 9% of the total time (see figure 3). All groups continued their work by drawing a position–time graph. One group worked together to create a position-time by using the whiteboard. The students in the other four groups all created their graphs individually, while simultaneously discussing how to interpret and represent the story as a graph. The majority of the work during this laboratory task was coded as processing data, corresponding to 84% of the total time. Two of the groups took time at the end of their work to discuss their results. These two episodes were coded as analysis of results, and amounted to 9% of the total time.

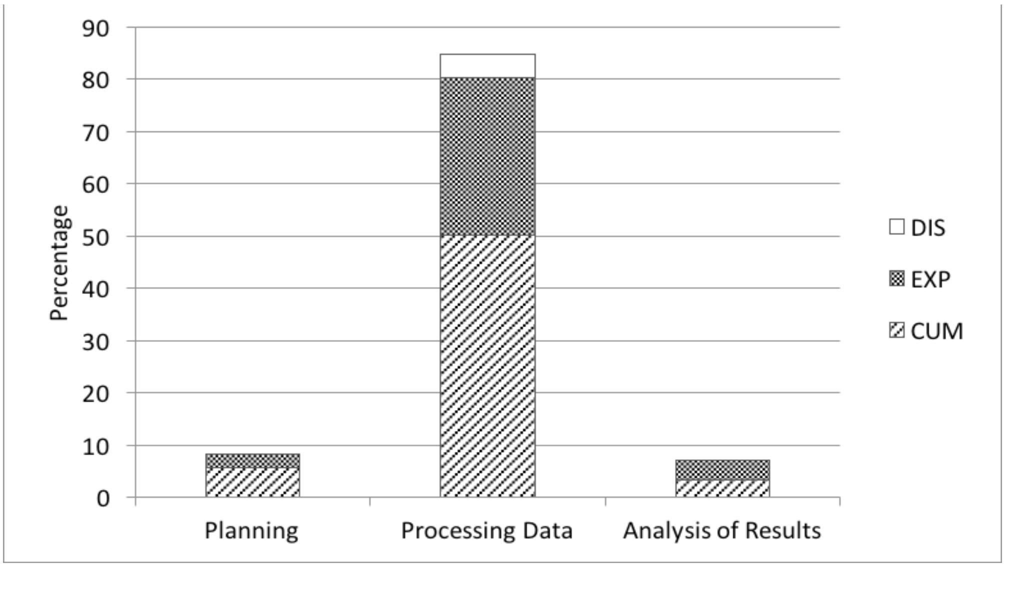

Figure 4: Position-Time Graph. Summary of activities and talk-types categorised with time as unit of analysis.

Analysis of students' communication. In this laboratory workstation, which was categorised as problem-based, the students had more intense discussions. In total, the work of all the groups was here inductively divided into 70 episodes of which 36 episodes, 59% of the time, were coded as cumulative talk and 32 episodes, 37% of the time, were categorised as exploratory talk. Two episodes were coded as disputational talk, corresponding to 4% of the total time (see figure 4). The drawing of the position-time graph generated several exploratory talks, in which some of the discussions concerned whether a motion could be represented with a partial negative position. The topic of these discussions stemmed from the actual task but diverged into another context. On these occasions, students used their prior experience to clarify and strengthen their explanations and arguments. A few of these talks also turned into disputational talks (see figure 4). The cumulative talk occurred most frequently when students thought aloud as they drew their own diagrams and checked to see whether the others in the group were doing their graphs in a similar way.

Station 3: The Motion Detector

Description and analysis of the task. The students were given a paper with 16 different position-time graphs. The task was to imitate those graphs by walking in front of a motion detector (see Appendix). The detector was connected to a computer and a program simultaneously drew a corresponding position-time graph and a velocity-time graph, as the distance between the person and the detector changed. The outcome of the activity was predetermined, and the procedure was categorised as given, since the students had been given graphs to imitate a motion with the help of a detector. In this case students drew conclusions based on experience, thus making the approach inductive. According to Domin's table, the descriptors indicate that this station could be defined as a discovery style of laboratory work.

Analysis of students' activities. The students found their roles quickly. One or two students usually took a place at the computer. Another student chose to walk in front of the motion detector and the fourth student took notes. This division of work within the groups usually persisted throughout the activity. Sometimes the students took turns walking in front of the detector. In the beginning, the teacher was often present and gave additional instructions about the equipment. The students seemed to have little difficulty in interpreting the graphs. Rather, the challenge for the students became trying to reproduce the given graph as accurately as possible. All data processing was exclusively done by a computer, which allowed the students to instantly analyse and comment on the graphs after each run. As a consequence, the students occasionally applied a trial and error approach, where instead of doing a thorough analysis, they chose to delete a graph and just try again based on intuition. The students worked for about 15 minutes and were engaged in several different activities during this time (see figure 5). This task generated significantly more, and consequently shorter episodes compared to the other three stations. In total, work of the five groups was coded into 188 episodes. Usually the students quickly talked through how interpret a graph as a motion, and then they immediately tested their theories by using the detector. The analysis of their results was, for the most part, brief, and involved either a confirmation of their predictions or how to make changes to improve the result. The following represents the cycle of activities: Planning, collecting data and analysis of results were repeated for each graph. Students in group B differed from the rest by choosing to work through three graphs and then sit down together around a table to analyse their results, which caused their time spent on the activities collecting data and analysis of results to diverge from the other four groups (see figure 5). In total, the percentage of time the students spent on each activity can be broken down as follows: Collecting Data 24%, Planning 20%, Preparing Equipment 8%, and Analysis of Results 48%.

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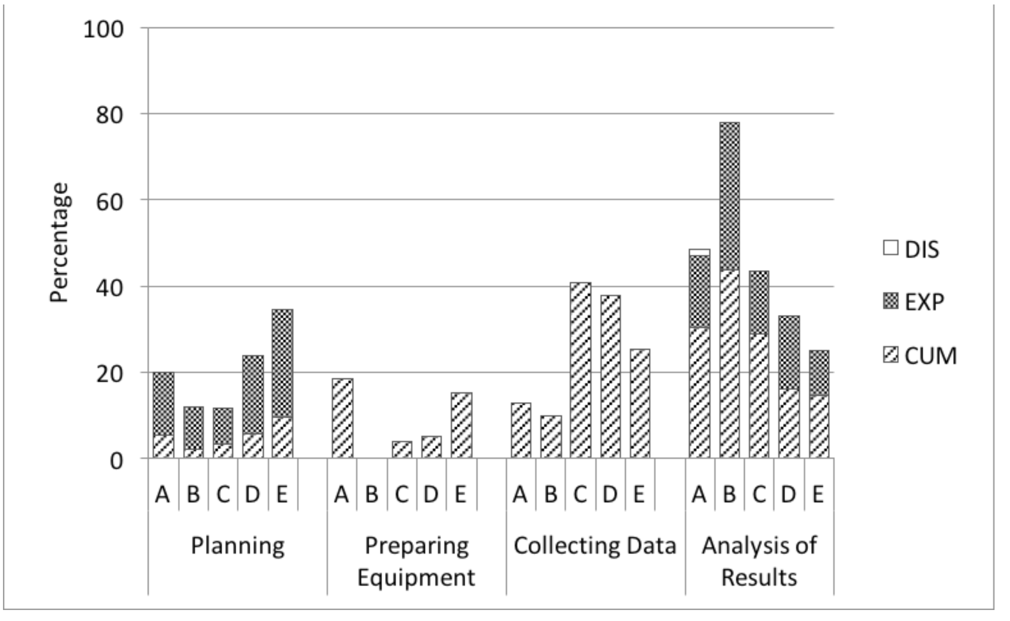

Figure 5: Motion Detector. Individual groups activities and talk-types categorised with time as unit of analysis.

Analysis of students' communication. In this task, which was categorised as a discovery style of laboratory work, 66% of the talk was cumulative, primarily involving direct instruction on what to do and how to walk in front of the detector. Much of the talk consisted of comments about what they were seeing on the screen, making the dialogue less consistent since they were not addressing their comments to anyone in particular. The remaining 34% of the talk was of an exploratory nature, where the students mainly interpreted graphs in the planning phase or during analysis of results (see figure 6). During the activities preparing equipment and collecting data, students used cumulative talk exclusively. All the episodes coded as cumulative talk are content-related in the sense that discussions always concern the actual task. The communication shifted back and forth between cumulative talk and exploratory talk as a result of the repetitive work process.

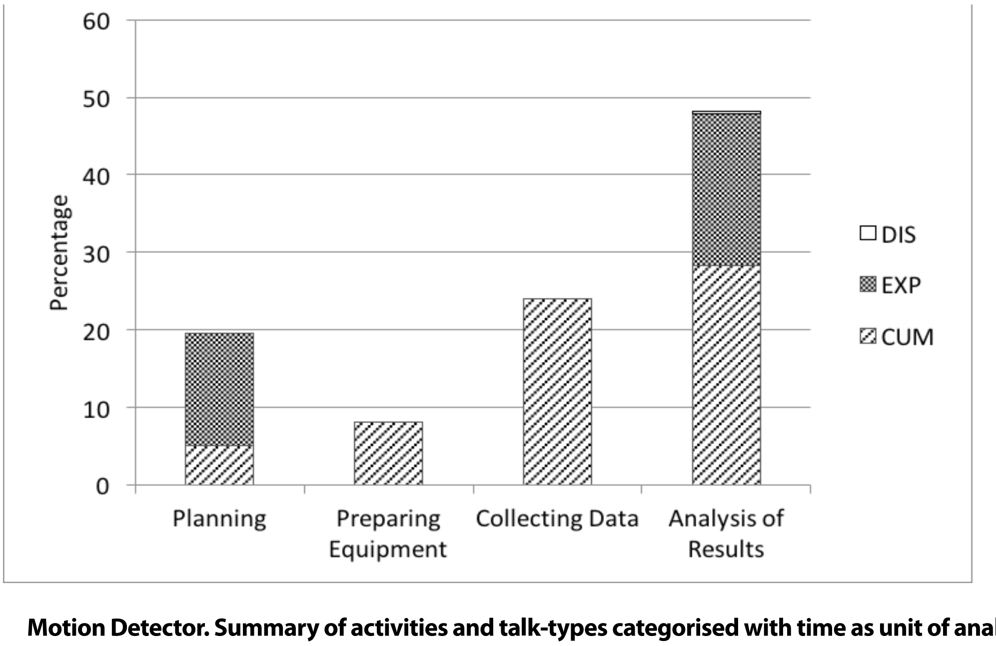

Figure 6: Motion Detector. Summary of activities and talk-types categorised with time as unit of analysis.

Station 4: The Free Fall

Description and analysis of the task. The task was to determine the velocity and acceleration of two objects falling to the ground, a ping-pong ball and a metal ball, by using a tape measure and three stopwatches. Students were also expected to discuss and compare their results with the value 9.82 (see Appendix). The students were instructed to measure the height from the window in the physics lab to the ground outside, and use the stopwatch to measure the fall time of the two objects. Students' tasks were to calculate accelerations and velocities and make unit transformations and decide which of the objects had the greatest acceleration. These worksheet questions, especially those that involved repeated measurements and calculations, consumed most of the available time and could be considered the main questions to be answered in this exercise. However, the question "Why does it deviate from 9.82?" differs in this aspect from the rest. This "Why?" question required reasoning and encouraged students to engage in discussions. No other task or question in this worksheet encouraged students to share or clarify their thoughts and understanding of acceleration as a concept. The procedure for the students to follow was given, since the teacher provided instructions on what to do and how to do it. The approach was deductive in the sense that they applied a formula to perform the calculations. The outcomes for all questions were undetermined but the value 9.82 was given as a reference for the acceleration calculations. The laboratory type that best conforms to this activity is the expository style. We inductively found 20 episodes based on activities during this 15-minute laboratory assignment.

Analysis of student activities. The five groups divided the work similarly. One student took a stopwatch and walked outside to measure the fall times and the height, and to throw the balls back up to the window. Two students, each with a stopwatch, stood by the window where they counted down, dropped the balls and measured the time. The fourth student took notes. Students in each group measured the distance from the window to the ground. Then they dropped the metal ball and the ping pong ball and measured the fall time. Four of the groups performed two measurements on both the ping pong ball and the metal ball. Group E spent considerably more time on Planning and Collecting Data than the other groups (see fig 7), and as a consequence they did not have enough time for Processing Data and Analysis of Results. Combined, the five groups used 38% of the time for Collecting Data. During the activity coded as Processing Data, corresponding to 34%, students sat down together and individually solved the equation $s=at^2/2$ for a. All the groups that calculated the accelerations obtained results within the range of 10 to 13 m/s^2. The probable cause of this large deviation in comparison to the gravitational acceleration constant is most likely the students' time measurements. Some groups discussed this deviation during the activity coded as Analysis of Results, but the unit of acceleration was discussed in all the groups. 21% of the time was used for Analysis of Results. Overall, the groups' work process was similar to the first workstation called Tape Timer. Both stations prompted a linear structure in completing the task - students started and finished one activity before moving to the next.

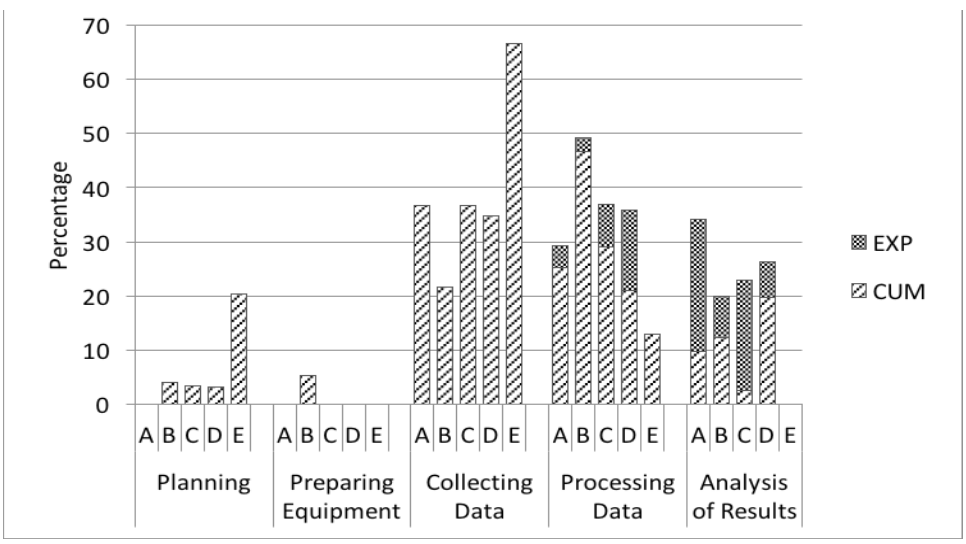

Figure 7: Free Fall. Individual groups activities and talk-types categorised with time as unit of analysis.

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Analysis of students' communication. 82 % of the talk was found to be of a cumulative kind, and 18 % of an exploratory type that contained more conceptual physics content (see figure 8). Comparisons between activities and talk-types indicate that collecting data and processing data predominantly generate talk of mainly cumulative character. The students moved into exploratory talk mainly when they reflected on the validity of their results and unit for acceleration. All the exploratory talks related to the actual work. None of the students in the five groups made links to previous experiences during discussions of their results. The students were clearly affected by the short time set for this activity, since they seemed to rush through the measurements, ignoring raised questions about the validity of measured times.

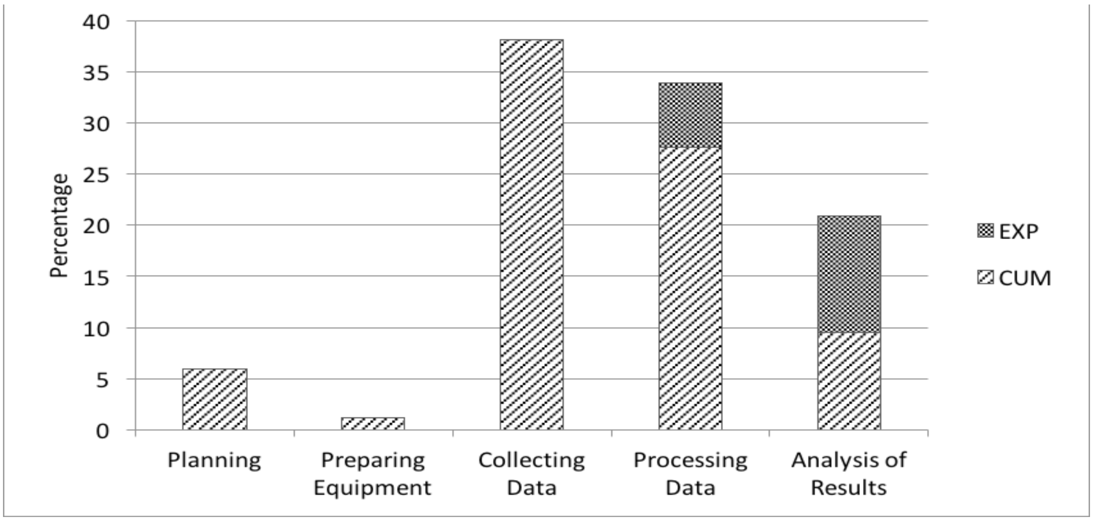

Figure 8: Free Fall. Summary of activities and talk-types categorised with time as unit of analysis.

Summary of Results

One purpose of this research was to answer the following first research question:

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

All four tasks combined, and distributed over 5 hours generated 71.5% cumulative talk, 27.3% exploratory talk and 1.2% disputational talk. Figure 9 shows how the three talk types are distributed across the four laboratory tasks.

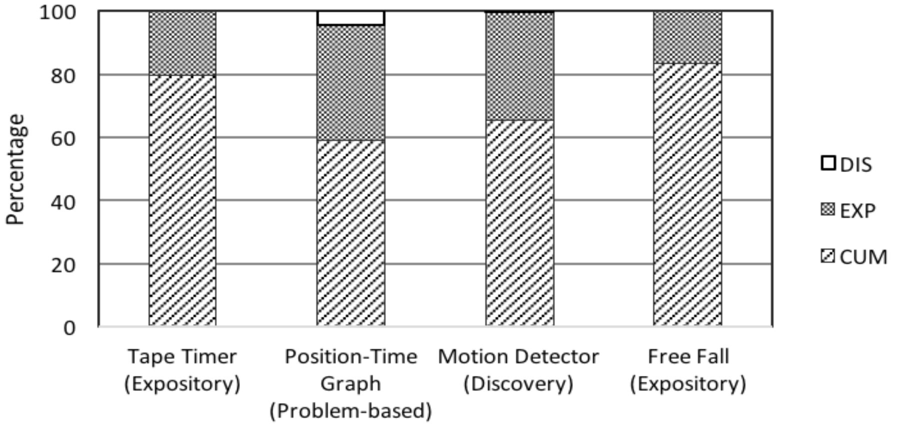

Figure 9: Summary of distribution of talk-types across the four laboratory tasks.

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Three different styles of laboratory work were identified. Expository, Discovery and Problem-Based style. Both the Tape Timer station and the Free Fall station were categorised as Expository styles of laboratory work. These two workstations generated 81.5% cumulative talk and 18.5% exploratory talk. The Problem-based style station 2 – Position Time Graph generated the most exploratory talk at 37% and 59% cumulative talk. 4% of the talk at station 2 was coded as disputational talk. The discovery-based style station 3 – Motion Detector generated 66% cumulative talk and 34% exploratory talk. In stations 1 and 4, which are identified as the expository style, the teacher gave thorough instructions for how to carry out the work, which meant that the students engaged in very little planning activity themselves (see figure 10). At stations 2 and 3, which were categorised as problem-based and discovery styles of laboratory work, respectively, the teacher gave thorough instructions for *what* the students were supposed to do but did not mention anything about *how* they should proceed with the work. In general, the students moved into more exploratory talk during the problem-based and discovery styles of laboratory work, compared to the expository style.

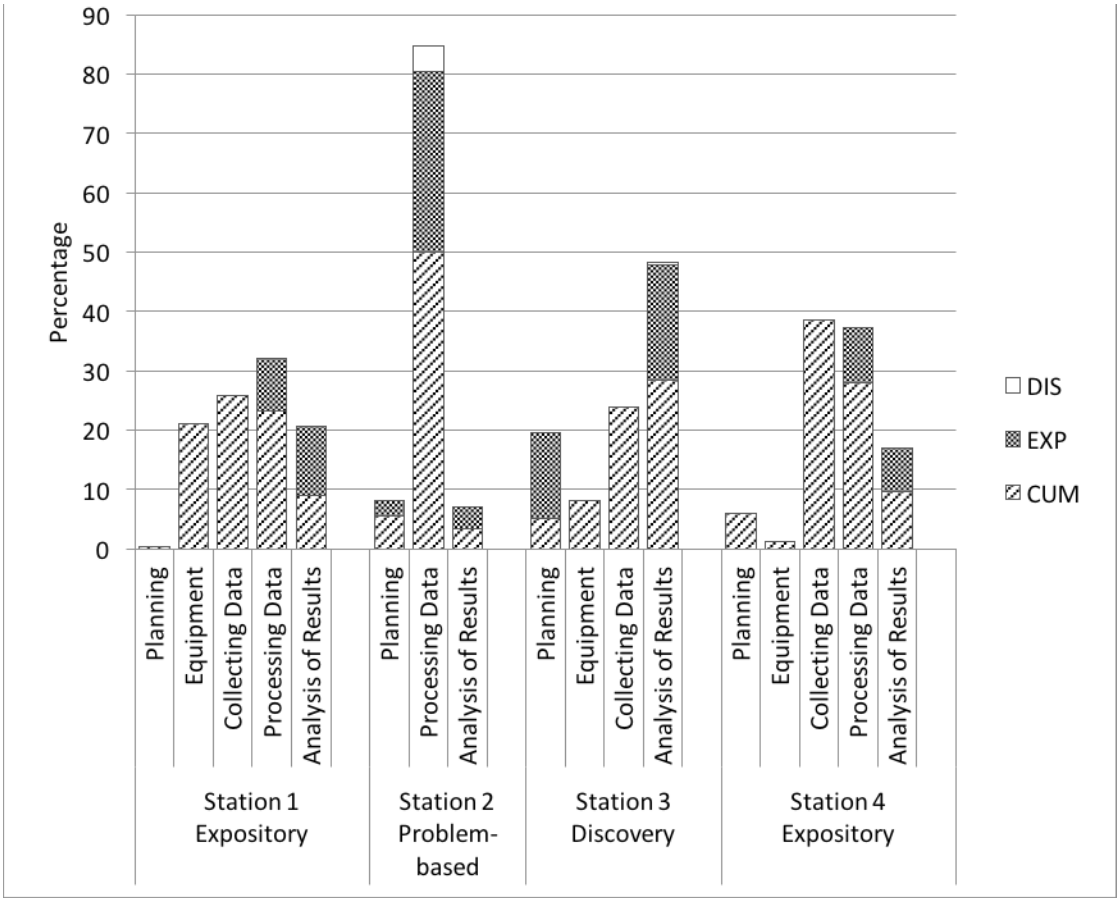

Figure 10: How the 15 minutes at each station was distributed over activities and talk-types.

Two separate, two-way ANOVA, tests were conducted to establish if there was any significant difference between the identified laboratory styles with respect to cumulative and exploratory talk, for the different groups of students. Too few episodes were coded as disputational talk in order to make a statistical comparison test between the laboratory styles with respect to disputational type of talk.

The first ANOVA test was performed to see if there was any significant difference between expository, problem-based and discovery styles of laboratory work with respect to the five-group communication, coded as cumulative talk. The result shows that there was no significant difference between the three styles of laboratory work with respect to how the cumulative talk is distributed. There was also no significant difference between the five groups, with respect to how the students' cumulative talk was distributed among the three identified styles of laboratory work.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The second two-way ANOVA test was performed to examine if there was any significant difference between the style of the laboratory work and between the five groups, with respect to talk coded as exploratory talk. Each of the five groups' total time of exploratory talk were summarised for each of the four workstations (see table 2)

Table 2. Total time in seconds, coded as exploratory talk for each of the five groups, distributed over the different workstations.

Group	Station 1 Tape timer	Station 2 Position-Time Graph	Station 3 Motion Detector	Station 4 Free Fall	Average
A	124	494	301	201	280
B	234	345	512	93	296
C	108	245	202	232	197
D	227	346	275	208	264
E	175	233	284	0	173
Average	174	333	315	147	

The result shows that there is a significant difference ($p < .05$), between the different laboratory styles with respect to how the exploratory talk is distributed (see table 3). There was no significant difference between the groups of students.

Table 3. Two-Factor ANOVA without replication, for episodes at each workstation and group, coded as exploratory talk.

Source of Variation	SS	*df*	MS	F	p-value	F crit
Rows	46610,2	4	11652.55	1.35	.31	3.26
Columns	136248,95	3	45416.32	5.27	.015	3.49
Error	103353,8	12	8612.82			
Total	286212,95	19				

Paired sample t-tests were also conducted between the different workstations with respect to time coded as exploratory talk. A significant difference was found between the expository workstation 1 and workstation 2, categorised as problem based; $t(4) = -2.92$, $p = .043$. There was also a significant difference between expository workstation 1 and workstation 3, coded as discovery style of laboratory work; $t(4) = -3.53$, $p = .024$. No significant difference was found between the two expository workstations 1 and 4, and between the problem based workstation 2 and the workstation 3, categorised as discovery style of laboratory work. A significant difference was also found between workstation 2 and 4; $t(4) = 3.71$, $p =.021$. No significant difference was found between station 3 and 4.

All sequences from the different laboratory work coded as activities and episodes were also summarised in order to answer the second research question:

What activities does the laboratory work generate and how do the activities relate with the talk-types between students?

The diagram in figure 11 shows that cumulative talk dominated in all activities. The activities Planning, processing data and analysis of results also seem to promote more talk of an exploratory nature than the other activities. Analysis of results is the only activity where all four stations are represented. Processing data was the primary activity during station 1, and station 3 and generated mainly talk of a cumulative character. Activities such as preparing equipment and collecting data generated only talk of a cumulative character. Processing Data generated mainly cumulative talk and was the dominating activity in station 1. Use of computer equipment in station 3 meant that students did not need to process any data themselves. The computer software transformed the data into diagrams automatically, and consequently more time was devoted to other activities such as analysis of results with mainly cumulative talk. Comparisons of talk-types distributed over the activities show that preparing equipment and collecting data generated cumulative talk exclusively. Exploratory talk occurred mainly during planning, processing data and analysis of results. The amount of disputational talk was fairly low and only occurred during processing data.

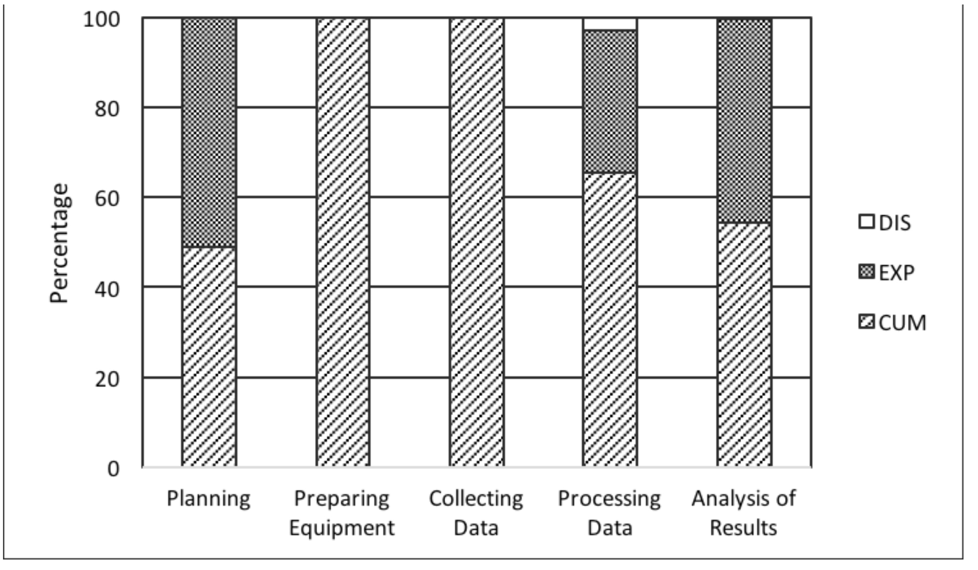

Figure 11: Summary of activities and talk-types categorised with time as unit of analysis.

Two separate statistical ANOVA tests were performed to examine if there were any significant differences between the activities and between the five groups, with respect to the total time of talk, coded as cumulative and exploratory talk respectively. The different groups' total talk time coded as cumulative talk was summarised for each different activity (see table 4). The largest amount of cumulative talk was found in the activity processing data and the smallest amount of cumulative talk was found in the activity planning.

Table 4. Total time in seconds, coded as cumulative talk for each of the five groups, distributed over the different activities.

Group	Planning	Preparing Equipment	Collecting Data	Processing Data	Analysis of Results	Average
A	53	311	689	714	452	444
B	133	127	509	1048	814	526
C	155	291	872	1031	455	561
D	145	172	763	850	401	466
E	271	420	953	770	120	507
Average	151	264	757	883	448	

The ANOVA test showed (see table 5) that the amount of cumulative talk students used varied between the different laboratory activities with statistical significance; ($p < .05$).

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ISSN 2538–7138 /Online/

Table 5. Two-Factor ANOVA without replication, for episodes in each activity and group, coded as cumulative talk.

Source of Variation	SS	*df*	MS	F	p-value	F crit
Rows	43636.56	4	10909.14	0.36	.84	3.01
Columns	1961589.36	4	490397.34	16.06	.000018	3.01
Error	488414.64	16	30525.92			
Total	2493640.56	24				

The same approach was used for the groups' total talk time coded as exploratory, where the time was summarised for each group with respect to each activity (see table 6). The largest amount of exploratory talk was found in the activities analysis of results and processing data, while the activities preparing equipment and collecting data did not generate any exploratory talk at all.

Table 6. Total time in seconds, coded as exploratory talk for each of the five groups, distributed over the different activities.

Group	Planning	Preparing Equipment	Collecting Data	Processing Data	Analysis of Results	Average
A	212	0	0	323	585	224
B	114	0	0	386	684	237
C	73	0	0	336	378	157
D	188	0	0	560	308	211
E	201	0	0	408	83	138
Average	158	0	0	403	408	

The ANOVA test showed (see table 7) that the amount of exploratory talk students used varied between the different laboratory activities with statistical significance; ($p < .05$).

Table 7. Two-Factor ANOVA without replication, for episodes in each activity and group, coded as exploratory talk.

Source of Variation	SS	df	MS	F	p-value	F crit
Rows	37288.16	4	9322.04	0.63	.65	3.01
Columns	828674.56	4	207168.64	13.96	.000044	3.01
Error	237417.44	16	14838.59			
Total	1103380.16	24				

Discussion

Method Discussion

By using Domin's categorisation scheme with the three descriptors outcome, approach and procedure a clearer differentiation of the four workstations could be made. The workstations were categorised into three different styles of laboratory work, still the workstations seemed to generate similar activities, which resulted in five defined activities. These activities were found to promote different amount of cumulative and explorative talk. The result of this study cannot be used to make broader claims, but indicates that there is a connection between the design of the laboratory work and the way it influences students to communicate with each other. A more controlled study such as an intervention where different styles of laboratory work are used to address the same task is worth pursuing in the future.

Result Discussion

The research sought to examine whether the style of the laboratory work related with students' communication. The analysis indicates that the three different styles identified promote similar activities, but differ in the amount of time students use for a specific activity. For example, in laboratory work with an Expository style (station 4), students used most of the time to process collected data, but used no time to plan their work. In laboratory work with discovery style (station 3) they used time for planning but no time to process data.

The research also shows that the character of the actual activities taking place as students accomplish the laboratory task influences the communication. Based on the findings, it is clear that the style of laboratory work is an important factor that serves to encourage different types of communication between the students. This research did not encompass influences of other factors, such as the teacher's ability to inspire and guide students' in their discussions, or different themes of inquiry, which most likely also have an impact on the quality of students' communication.

It is important to stress that even if three different styles of laboratory styles were identified in this research, the degrees of freedom remained low, since the teacher decided what they were supposed to do in all four given tasks. The teacher informed the students *what* they were supposed to do for each of the four given tasks. In addition, for the two expository tasks, the teacher also emphasized *how* they should proceed with the work. Students were never explicitly told what they were supposed to learn, which according to Jacobsen (2010), could have an impact on students' learning outcomes. Despite this, the laboratory tasks used in this research were effective in sense that the students did what the teacher intended for them to do, according to research about the effectiveness of laboratory work (Abrahams & Millar, 2008; Abrahams & Reiss, 2012).

Problem-based and discovery-based styles seem to generate more exploratory talk than the traditional expository style of work, which is in alignment with Katchevich et al. (2013) who found that students' discourse during inquiry experiments in chemistry was richer in arguments in comparison to confirmatory-type experiments. This does not imply that all expository styles of laboratory work should be eschewed. The quality of students' discussions also depends on the quality of their investigations (Kind et al., 2011). Before students can be expected to devote themselves to truly inquiry-based investigations, they also need to be taught and trained in how to perform a systematic investigation. When students possess these tools, and feel familiar within the physics discourse, the quality of their physics talk can be expected to improve. Laboratory work encompassing expository, problem-based and discovery styles may, if used with variation, help students understand different aspects of physics as a disciplinary discourse.

When Edwards and Mercer (1987) highlight 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, particularly with each other, should be considered as very important moments. Mercer (2004) means that exploratory talk is the most valuable form of educational conversation, which gives students opportunities to reflect upon old knowledge and transform it into new knowledge. The research shows that activities such as planning, processing data and analysis of results produce talk of an exploratory character, but for this to happen physics teachers must realise the inherent educational value of mastering the language of physics and start to design the laboratory work accordingly. Oyoo (2012) points out that for effective teaching to occur, the teachers need to attend more to the nature of the instructional language of the science classroom. Maloney and Simon (2006) advocate group activities in science education where students have the opportunity to develop the ability to reason. Based on this research results, it is clear that the context of laboratory work can create an appropriate environment for joint consideration and reflection. Both teachers and students need to understand the importance of communicating physics to apprehend a better conceptual understanding of the subject, which is not the present case (Högström, Ottander & Benckert, 2010; Oyoo, 2012).

During laboratory work, the students in the physics classroom have plenty of opportunities to communicate, since students often work in small groups to complete laboratory tasks. The research on efficacy of laboratory work focuses on whether students accomplish what the teacher intended for them to do and learn. Quite often, learning outcomes are evaluated as gains in conceptual knowledge, and criticised to be low. If engagement in

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dialogue shapes students' educational progress and intellectual development in general (Mercer & Littleton, 2007) and *talking physics* is the key to learning physics, in the sense that you become a person who can communicate with others about the physics discipline, then the analysis of how and what students discuss during practical work is relevant knowledge. The next step in this research will be to analyse the three talk types at both a linguistic and a cognitive level, based on interaction and content, to see if that could be a viable approach to further exploring how different talk-types shape students understanding and progression.

Even if cumulative talk is also seen as striving for consensus, this talk type is not considered to have as much educational value as exploratory talk (Mercer, 2004). The research shows that a majority of the talk between students during laboratory work is of cumulative character. During activities such as preparing equipment and collecting data the cumulative talk seems to inform them about their next step, as they are seeking and sharing information. In general, cumulative talk seems to keep the students on track and guide them forward. An interpretation is that, in a laboratory context, these cumulative talk sequences can act as a base and reference for students in their forthcoming exploratory talk dialogues. In order for this to occur, students must be given time and opportunities for joint consideration and reflection upon their work.

Disputational talk as a form of organised debate has been a pedagogical tool when teaching students argumentation skills. In this research, very few episodes were coded as disputational talk, which most likely is a consequence of the relatively short time students spent at each workstation. Even so we can see that the ability to engage in scientific argumentation is important, but so is the ability to argue from a value-based and experiential perspective. If students' communication had been studied over a longer period of time, more disputational talk of such character could be expected to be found in activities where students also often engage in exploratory talks. In activities such as planning and analysis of results, the quality of students' conversations is related to and revolves around the individual student's own interpretation of physics and conceptual understanding. It is therefore important that teachers design and further develop laboratory activities that support these forms of communication.

Conclusions and Implications

There is an existing gap between the research field of physics laboratory work and the field of students' communication. More knowledge is needed about students' communication during laboratory work, for researchers and teachers to be able to design and implement effective physics laboratory work lessons. This research is a contribution in that respect, as it shows that different laboratory work activities promote different types of communication between the students. Based on the results from this research it is therefore recommended that physics teachers should consider students' communication as an important didactical purpose.

This finding is important from several aspects:

- It emphasises the design of the laboratory work from a sociocultural perspective, where students' interaction is fundamental for new knowledge to evolve. Students have in general few opportunities to naturally and freely use and practice their physics language, which is necessary if students are expected to embrace the special discourse of physics. Moments where students engage in exploratory talks are thus desirable and valuable. It is during these discussions students challenge their existing understanding and create new knowledge.
- By comprehending the importance of letting students communicate physics, teachers can with knowledge of this research easier design modules of laboratory work that fosters conceptual understanding through peer interaction. The effectiveness of the physics laboratory work can hence be expected to increase, if it incorporates more activities that promote exploratory talk amongst the students. By redesigning laboratory tasks, so that students use more time to activities such as planning, processing data and analysis of results, more exploratory talk between students can be expected to occur. Problem-based types of laboratory work is favourable in that respect where students are given a concrete task to solve, or a question to answer. Students are in such situations contested to suggest different methods and discuss its possibilities and limitations.

This research contributes with an additional piece of the puzzle, concerning the effectiveness of the physics laboratory work. More qualitative research concerning students' communication during laboratory work is though needed to better understand to what extend and in what way these different talk types contribute to students' learning.

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Appendix

Laboratory work - Motion

Station 1: Determining a value of the gravitational acceleration *g*.

Material: tape-timer equipment, 1-kg weight, ruler.
Mount a 1,5 meter-long paper strip on the tape-timer and attach the weight that will fall down on the foam material. Let a student turn on the tape-timer and then drop the weight. Start measuring where you can see dots from the tape-timer and measure the distance to the fiftieth point. This is the distance the weight has fallen during half a second. Use these values when you solve the formula $y=at^2/2$ for *a*. What is the value of *g*? Does it deviate from 9,82? Why?

Station 2: Position -Time graph after a story

Material: Worksheet

In order to describe a motion with a position-time graph the motion has to be a linear, the entire motion must take place along one and same path, that does not need to be straight.

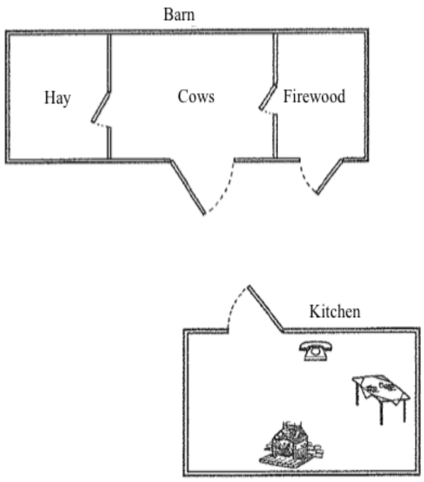
The Task: Describe the following events in a position-time graph.

"Karin and Sven live on a small farm in Alfta, were Karin takes care of some cows. Think of the farm seen from above according to figure 1.

> 'Karin has just finished an early breakfast at the kitchen table. She stands up to go out and milk the cows. Just as she enters through the farm door the phone rings, so she must run back and answer. After the call see notice that the fire in the wooden stove is about to go out, so she walks to the woodshed and retrieves some firewood, then back to the kitchen and makes a fire. Thereafter she goes back out to the barn, gets hay for the cows and milks them.'

a) See figure. Draw a path that Karin can follow until she answer the phone.
b) Describe how Karin must walk when she goes to get firewood and makes a fire so you can continue the diagram until she comes to the barn door the third time.
c) Why must the diagram be finished then?
d) Draw the diagram. Let it begin when Karin stands up at the kitchen table. You can improvise distances and times that are reasonable."

Figure 1



Station 3: Position-time-graph and velocity-time-graph with Go-motion.

Material: Computer, Go-motion
Beside the equipment there are papers with 16 different graphs. The purpose with this laboratory work is to try and imitate the distance-time graphs by walking in front of a motion detector. Which graphs are easy, and which are difficult to imitate? Why? Under the distance-time graph there is a velocity-time graph. With what velocities have you moved? What does positive and negative velocity mean? What is the difference to speed?

Station 4: Free fall (almost)

Material: tape measure, stopwatch, metal ball, ping-pong ball.
Measure the height from the window in the classroom down to the ground outside. Use a stopwatch to check the fall-time for the metal ball and the ping-pong ball as they are dropped from the window. What is the balls accelerations if you use the formula $y=at^2/2$ and solve it for a? Why does the value deviate from $g=9,82$? Which one of the balls has the greatest acceleration? What is the balls velocity at impact with ground if you use the formula $v=at$? What is the velocity in *km/h*?

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