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

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ABSTRACT

In this case study, we explore students' communication during practical work in physics at an upper secondary school in Sweden from a sociocultural perspective. We investigate the relation between the interaction and content of students' communication and outcomes of their actions, with the purpose of finding new knowledge for informing teachers in their choice of instruction. We make discourse analysis of *how* students interact but also of *what* students are discussing in terms of underlying content at a linguistic and cognitive level. Twenty students divided into five groups were video recorded while performing four practical tasks at different stations during laboratory work about motion. An analytical framework was developed and applied for one group to three parts of the transcripts in which three different talk-types occurred. Discursive, content, action and purposive moves in the process were identified for each talk-type at both linguistic and cognitive levels. These moves represent information concerning what the teacher actually assigns students to do, and how students make meaning of the activities. Through these different communicative moves, students experience how laboratory work can enhance their competence to collaborate in a scientific environment with complex practical and theoretical questions to solve quickly. Implications of the findings are discussed.

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Communication; discourse analysis; interaction; laboratory work; physics education; practical work; talk-types

Introduction

The research and general debate about physics laboratory work in upper secondary school have largely been concerned with learning outcomes, or efficiency in terms of motivating students to study science (see e.g. Abrahams, 2009; Osborne, Simon, & Collins, 2003), but there is a lack of reporting about what students actually talk about and do *during* the laboratory work or inquiry, and the outcomes of their actions. We would like to contribute with a study that focuses on the way to systematically analyse discourses *during* their task, in order to gain new knowledge that may be beneficial when teachers consider their choice of instruction. To study communication as teachers and student talk in the classroom began with Barnes and Todd (1977) and is still productive (Mercer & Dawes, 2014). Researchers find that one important factor in making the laboratory work function as

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an active learning environment is to provide the students with time to talk and discuss what they are doing (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000; Lemke, 1990; Renner, Abraham, & Birnie, 1985). 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, 1995, 2000; Mortimer & Scott, 2003; Vygotsky, 1978).

We argue that in lessons with small group work, like laboratory work, student communication and opportunities to talk become important for possible learning outcomes, that is, all kinds of outcomes from their actions. When you study communication (Lemke, 2000) and meaning-making (Mortimer & Scott, 2003) in the physics classroom, you observe that the teacher and students engage in interactions that can be of very different character depending on the purpose, planning, and staging of the teaching and learning that are supposed to take place. Lemke (1990) finds laboratory work as something different from other physics lessons and other subjects. During laboratory work, the type of talk going on between the students can either have a conceptual and theoretical underpinning related to the topic of interest, or be related to the narrative of how students collaborate to get through laboratory and inquiry procedures. It is evident that students are talking, but there is also non-verbal activity. Lemke (1990, p. 157) expresses his doubts about how much science students learn from laboratory work, since 'students do not seem to have enough command of the language they need to be able to figure out what is really going on in the lab while it is happening'. Similar ideas are mentioned in review articles of laboratory work (see e.g. Abrahams & Millar, 2008; Hofstein & Lunetta, 2004; Lazarowitz & Tamir, 1994; Lunetta, 1998). Another general statement from the research literature is that 'the fundamental concern for many students while in the laboratory is completion of the task, and that this concern can overwhelm any serious learning possibilities' (Hart et al., 2000, p. 656).

We find that student talk has not yet been investigated as the interactive tool to master the complexity of school physics inquiry, and wonder whether scrutiny and analysis of student communication during the different steps of laboratory work could provide insight into both the students' 'doing' and 'understanding' of the scientific processes.

Practical work as laboratory work or inquiry

The interest in science laboratory work in schools has changed from what we learned from the laboratory work tasks used in science teaching at upper secondary schools in Europe in the beginning of the century (Tiberghien, Veillard, Le Maréchal, Buty, & Millar, 2001) towards inquiry and scientific practices described as in A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas NRC (2012), or in Next Generation Standards (2013). Several projects supported by the European Commission offer coordination, support and professional development for teachers to shift teaching and learning towards inquiry-based science education (IBSE) approaches (e.g. S-TEAM, ESTABLISH). The main purpose of all laboratory work, according to Tiberghien et al. (2001) is to encourage students to create *links* between the domain of observables and 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 of using the ideas meant to be developed, or employ these ideas in a different context. Tiberghien et al.

(2001) list three broad purposes of doing 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. Abrahams and Reiss (2012) mean that science teachers' plans do not incorporate explicit strategies to assist students in making links between their observations and scientific ideas. Lunetta, Hofstein, and Clough (2007) stress that teachers must be assisted in engaging students to optimise the potential of laboratory activities that promotes different learning goals in science education. We not only agree with these authors but also interpret those statements as a need for more research about what is happening *during* these laboratory activities, in terms of how students make progress in their given tasks. The US Next Generation Standards encompass scientific argumentation as a more central component with a focus not only on science content, but also on the ability to do practical science work and understand the process of scientific inquiry. The standards contain eight essential practices ranging from 'asking questions' and 'developing and using models' to 'engaging in argument from evidence' and 'evaluating and communicating information' (Llewellyn, 2013). In laboratory work, where teachers give students thorough instructions what to do, how to do it and sometimes also what to expect, students are supposed to express links between observables and ideas. In IBSE approaches, they are supposed to learn scientific argumentation and be able to navigate the process of scientific inquiry. Even if traditional laboratory work and IBSE are both student-centred instructional approaches, student communication as *informal reasoning* (see e.g. Zohar & Nemet, 2002) during laboratory work in physics has not yet been in focus for its own sake.

Findings in literature that support the study's intentions

By tradition and accessibility, laboratory work in physics is often accomplished as small group work, which naturally involves oral communication between students. Bennett, Hogarth, Lubben, Campbell, and Robinson (2010) argue that for discussions in small groups to be effective, students need to be explicitly taught how to develop arguments and characteristics associated with effective group discussions. Mercer, Dawes, and Staarman (2009) stress the importance of teachers ensuring that group activities are well designed to elicit debate and discussion. Language is our prime tool for thinking collectively, according to Mercer (2015), and Mercer emphasises that student must learn how to use this tool. We agree, but argue that an important issue is that the time for informal reasoning between students and the 'talk space' they need for inter-thinking (Mercer, 2000) has a tendency to get lost in new teacher-led activities.

Bennett et al. (2010) recommend in their analysis of the efficiency of small group work in science, that such 'data might benefit from established discourse analysis techniques developed in other subject areas such as in (Barnes & Todd, 1995) and (Mercer & Littleton, 2007)'. We will follow this recommendation. Mercer and Littleton (2007) elaborate how collective construction of knowledge is achieved, and how engagement in dialogues shapes students' educational progress and intellectual development. We believe that if this process could be modelled, then both *how* and *what* students talk about must also be considered. Barnes and Todd (1995) show how the different types of communication between students reveal the various types of activities in which they are engaging, but on a deeper level, it also reveals their intentions and meaning-making interactions. They explored science group-work discourses on both linguistic and cognitive level, but only *discoursive* moves in the process.

In the process of laboratory work, moves become important as a sign of what is going on. Searching in the literature for studies on moves, we found that Öhman and Öhman (2013) used a combination of epistemological moves and pragmatic discourse analysis to investigate students' discussions about climate change, in order to clarify the process of knowledge constitution and the content of the constituted knowledge. Their conclusion is that it is important that teachers pay attention to governing processes among students and occasionally challenge students' common views in order to allow for alternative views.

Communication and students' use of different talk-types

Barnes and Todd (1995) found that the pupils working in pairs used exploratory talk during laboratory activities to solve conceptual problems, and that they made specific discursive moves to proceed towards conclusions and agreements, like *challenge,* to question someone's scientific explanation, or *extending*, to add new information and develop each others' ideas. They found how small group communication enhances learning by 'giving new experiences, which leads to a reshaping of a wider area of understanding, which may later affect how other similar events are interpreted' (Barnes & Todd, 1995, p. 11). In their extensive scheme for analysing group talk and the social and cognitive functions (Barnes & Todd, 1995, p. 79), the discourse moves guide how the talk in small groups becomes exploratory. The students' informal reasoning during practical work showed distinctive discursive moves, and student communication also showed on a cognitive level 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.

Mercer (1995) finds three different levels of analysis: (1) the linguistic level, where talk is studied as spoken text, in terms of how students talk to each other, (2) the psychological level, where students' talk is studied as thought and action and (3) a cultural level, where according to Mercer, exploratory talk is highlighted as the 'educated' discourse that represents the kind of reasoning 'that is valued and encouraged in cultural institutions of formal education' (p.106). In accordance with Barnes and Todd, Mercer finds how exploratory talk: (1) combines, at the linguistic level, the speaker's challenges and requests for clarification with responses that provide explanations and justifications and (2) takes into consideration, at the cognitive level, the views of all participants, with explicit agreement preceding decisions and actions (Mercer, 1995).

Based on the previous literature cited above, we define communication as referring to the joint understanding students create through collaboration during the laboratory inquiry with regard to talk, content and interaction during activities. Barnes and Todd (1977) mean that '*moves* must 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 and Todd (1977) exemplify such discursive moves by breaking them down into steps as *Qualifying, Challenging* or *Extending*, in order to describe how a talk-sequence develops. In our analysis of student communication, we search not only for these predefined discursive moves, but also for undefined moves at both a linguistic and cognitive level in the dimensions of interaction and content. We define interaction as a representation of *how* students talk to each other at a linguistic level, and *how* they act towards each other on a cognitive level. Content is seen as *what* students talk about at a linguistic level, and *what* underlying purposes student express during group discussions on a cognitive level. In our analytical framework, we have combined the previous work done by Barnes and Todd (1995) and Mercer (1995) and extended it to also comprehend the dimension of content at both a linguistic and cognitive level (see Table 1).

Our hypotheses are that a more comprehensive discourse analysis, that also include moves like action moves, content moves and purposive moves (see Table 1), can be a tool that helps us further untangle the complexity of understanding students' meaning-making process through collaboration at both a linguistic and cognitive levels.

Purpose and research questions

The purpose of this study is to clarify how students' communication is structured during the process of the group laboratory work in physics at upper secondary school. This is important as a link between *how* students communicate and *what* students communicate about, during laboratory work in physics, would be useful as both a theoretical contribution for further research and a pedagogical instrument for teachers in their effort towards planning and designing effective laboratory work in the physics subject.

Table 1. Principle for discourse analysis. Operationalisation based on adaption from Barnes and Todd (1995) and Mercer (1995).

	Interaction (HOW?)	Content (WHAT?)
Linguistic level Talk as moves in the dialogue and in the content	*Discursive moves:* How do they speak to each other?	*Content moves:* What content is in focus and what topics are discussed?
Cognitive level Talk as actions and thoughts	*Action moves:* How do the students act when they make progress in the task?	*Purposive moves:* What student purposes does the talk sequence express?

The research questions are:

(1) What student interactions are communicated during laboratory work in physics when different talk-types are in use?
(2) What is the content being communicated during laboratory work in physics when different talk-types are in use?

Method

Participants and procedure

This study is especially focusing on one laboratory session presented by a Swedish teacher to his class of 20 students at upper secondary school, as a typical inquiry designed to give students practical experience of how to investigate linear movement with constant acceleration in physics. Both the teacher and students were, prior to the lesson, informed about ethical guidelines from the Swedish Research Council and had given their written permission to take part in a project about the role of laboratory work in physics. The data analysed in this study originate from the first video-recorded lesson in that project. The teacher designed the laboratory session himself in accordance with the structure of the course, without any requests or guidance from the researchers. Neither the teacher nor students were at the time of the actual lesson aware of this study's design. The teacher and the class had just started working on the topic uniformly accelerated motion and this laboratory lesson consisted of four separate workstations. At the first workstation, students were supposed to experimentally calculate the gravitational acceleration constant, by using a 1 kg weight, a tape timer and a given formula for how the fall distance depends on time and acceleration. At the second workstation, students were asked to discuss and together draw a distance time graph, based on a given story about a person's motion pattern. The third workstation was of a more discovery character, where students were asked to walk in front of a motion detector connected to a computer, and try to imitate distance time graphs given on a separate paper. At the fourth and final workstation, students were asked to drop a ping-pong ball and a metal ball from the classroom window, on second floor, down to the ground outside and measure the fall distance and the fall time for each of the dropped items. The task was thereafter to use a given formula and calculate the items' acceleration and velocity and compare the results with the acceleration of the gravitational constant. Each workstation was set up in separate classrooms to facilitate good audio and video recordings. The teacher started the laboratory lesson by handing out a written worksheet and dividing the students into four groups. Thereafter, the teacher informed them thoroughly what to do at the location of each workstation. Students were given 15 minutes at each station and on teacher's command, they were asked to move to the next station in a cyclic procedure. During students' implementation, the teacher took a much more passive role in order not to mediate students' conversation, walking around, observing and listening to the students as they worked with the given task. In the end, all students were gathered and the teacher ended the lesson by reminding the students to individually write down and finish eventual missing calculations and conclusions. The video recordings of all groups' work were initially observed. All the different groups worked concentrated during the 15 minutes at each workstation. One group of four students was chosen for a deeper analysis. Students in that group participated actively in the practical task and were engaged in several discussions with different types of talk.

Method of analysis

To answer the research questions, we performed a discourse analysis of students' communication using a qualitative thematic approach (see e.g. Braun & Clarke, 2006) during students' laboratory work in physics. The recorded video films of one group's laboratory work were transcribed. The video recordings and corresponding transcripts were thereafter divided into shorter episodes based on activities students were engaged in, such as *Planning, Preparing equipment, Collecting data, Processing data* and *Analysis of results*. The episodes were then deductively coded into one of three different talk-types, based on Mercer's descriptions. The excerpts were coded for talk-types by both authors individually. The video recordings together with the transcripts representing exploratory talks were studied repeatedly searching for discursive moves defined by Barnes and Todd (1977). Both video recordings and transcripts from the cumulative and disputational talk episodes were then investigated for characteristic undefined discursive moves at a linguistic level, through an iterative inductive open coding process (Mayring, 2001). Both authors participated in the analysis where similar moves were discussed and finally merged into new broader identified moves, under the main category *Discursive moves,* representing cumulative and disputational talks, respectively. This analytical process was repeated three times for each one of the transcribed talk-types, in the search for specific moves representing the other three main categories: *Action moves*, *Content moves* and *Purposive moves*.

The *Discursive moves*- and *the Action moves* category both relate to how students interact, whereas *Content moves* and *Purposive moves* relate to the content students talk about, at both a linguistic and cognitive level. We consider these three categories together with the predefined category *Discursive moves* to be cornerstones in our tentative analytical framework matrix, earlier presented in Table 1.

Validity and reliability

To strengthen the identified moves' reliability, video recordings of three additional groups doing the same laboratory work were in retrospect examined and coded for moves in the four main categories by both authors individually. The inter-rater reliability test resulted in an 83% overall agreement with respect to identified moves. It is here important to stress that this inter-rater reliability test was done in the same laboratory work context. Identified content moves can most likely be expected to differ depending on what type of laboratory work is investigated.

The trustworthiness of the study, in terms of how well the analytical model helps us to clarify *how* and *what* students talk about, is validated by the fact that our analytical approach is grounded in previously well-established framework originally created by Barnes and Todd (1977). Their introduction of exploratory talk was supplemented by Mercer (1995) to also comprehend disputational and cumulative talk. In this study, we build upon their, previous proven successful, analytical approach to also include moves for all three talk-types at both a linguistic and cognitive level. The combination of using existing, and searching for new, moves to answer our two research questions strengthens this study's validity. To further ensure that our interpretation and use of the analytical framework were legitimate, we presented the model at a smaller research seminar. Six senior researchers who were asked to use the model on a shorter transcribed excerpt all succeeded to use the analytical framework and describe how students interact and what the content was about in terms of the four moves. They found the presented method useful in terms of emphasising *how* and *what* students in groups were talking about in the context of laboratory work.

Results and analysis

We provide three excerpts to show and exemplify how the talk-types were identified from the empirical data and analysed from the operationalisation in Table 1. In the transcripts, parentheses with a number represent seconds of pause in an utterance and words within brackets are used to symbolise where two or more students talk simultaneously.

Excerpt 1 – Cumulative talk during the activity collecting data

This excerpt is from an activity where the task was to calculate the velocity and accelerations of a ping-pong ball and a metal ball dropped from a window, and compare these values to the gravitational acceleration constant. The conversation presented in the following transcript occurred during an activity coded as collecting data. The Group started the laboratory work by measuring the height from the window to the ground. They needed the distance for later calculations of the speed and acceleration of the two objects. The communication starts (Lines 1, 2) in the excerpt on the linguistic level when George initiates (a linguistic discursive move) the interaction, and takes the approach (a linguistic content move) of suggesting a starting action. On a cognitive level, he promotes interaction by instructing how to 'take it from here and release' the ball (a cognitive interaction move), and with a purposive move on how to use the equipment (a cognitive content move).

(1) George: Let's take it from here and then we release it.
(2) George: Hey! It's zero there.

Paul confirms this action (Line 3) and elaborates the action further (Line 5).

(3) Paul: But we are the ones who measure that.
(4) George: Yes, you have to start at zero.
(5) Paul: Well, it begins at this tip.
(6) George: It begins at minus there you'll see.

George initiates to give further instructions for the measurement (Lines 6–9) and Paul confirms and repeats this instruction (Line 10).

(7) George: No it does not!
(8) George: No no no, you see that it's zero there a bit further on further on (2) it's zero. There! There! Hold it to the ground.
(9) George: Do you hold it to the ground? You'll have to stretch it!
(10) Paul: Keep it down there.

Finally, George summarises and adds a result (Line 11), and before suggesting a new action, John writes the result down (Line 12).

(11) George: So, hm what is it? (3) 4.. 4,7
(12) John: Wait I'll write it down.
(13) George: Write it down!

Finally, Paul makes a request to throw the tape measure down to the ground to confirm the action (Line 14), and he also repeats the result; the distance is 4,7 m (Line 15). George ends the session with a request to let the tape measure go (Line 6). The duration of the excerpt is 57 s.

(14) Paul: Tom! If I throw this down you throw it back up.
(15) Paul: 4,7 meter, John has written that up.
(16) George: You can let go now!

Linguistic level – Interaction–discursive moves: How do they speak to each other? The communication between the students in this episode does not contain many direct questions and answers, but rather more utterances in which they tell each other what to do. The cumulative character of the discourse is evident from the discourse moves that are forming a result with all participating group members and contributing to the final result. This cumulative talk starts with an initiative for action (Line 1), and ends with a request for action (Line 16). The group typically uses moves like requests for actions (Line 9), confirmations and repetitions (Lines 12 and 13), which puts this transcript into the category of cumulative talk with discursive moves (see Table 2).

Linguistic level – Content; content moves: What content is in focus and what topics are discussed? The dialogue is content-related in the sense that the students talk exclusively about what they are doing at the moment. The students talk about what they are going to measure and how to read the scale on the tape measure. George is instructing Tom who is standing on the ground outside holding the tape measure. They repeat the measured value and write it down. The discussion in this transcript is formed by content moves found in (Table 3).

Cognitive level – Interaction; action moves: How the students interact through communication and make progress with the task. The interaction is characterised by everyone contributing to the progression of the task, and all are pursuing the same goal. All students seem to be aware of what to do, and work is focused on performing the required measurements. There are few questions asked – instead, they tell each other what to do in a friendly but authoritative manner, like: –*Hold it to the ground!* (Line 8) and –*Write it down!* (Line 13). This type of interaction is likely to build both the individual's, but also the groups' determination to make progress with the task. A majority of the talk in this cumulative talk episode consists of actions moves defined in (Table 4).

Cognitive level – Content; purposive moves: What purpose does the talk sequence express for the students? The completion of a small task, in this case a performed measurement, contributes to the progression of the main task. The talk sequence about how to

Table 2. Coding scheme for a cumulative talk at a Linguistic level – Interaction.

Discursive moves	Definition	Example
Request for actions	A student requests another student to contribute to the work.	George tells Tom to stretch the measure tape and later to let it go (Lines 9 and 16).
Confirmations	A student confirms by answering someone's utterance or question.	Paul confirms George's request for actions (Line 10).
Repetition	A student repeats someone's statement.	John repeats the measured value (Line 15).

Table 3. Coding scheme for a cumulative talk at a Linguistic level – Content.

Content moves	Definition	Example
Implementation	Students come with suggestions how to proceed with a measurement.	The transcript starts by George suggesting how to perform the measurement (Line 1).
Use of equipment	Discussion of how equipment should be used.	George and Paul tell Tom how to measure the height (Lines 4–10).
Taking notes	Measured values are forwarded to be noted.	John tells the others that he will write down the measured value, and George instantly repeats him (Lines 12–13).

Table 4. Coding scheme for a cumulative talk at a Cognitive level – Interaction.

Action moves	Definition	Example
Declaring	A student explains how to use the equipment.	George explains how to read the tape measure (Line 8)
Instructing	A student tells others what to do without asking.	George gives Tom instructions on what to do (Line 9)
Requesting	A student asks pragmatic; for example, for the result of a measurement.	George asks for information (Line 11)
Informing	Forwarding a measurements result.	Paul tells Tom the result (Line 15)

measure the height contributes to a shared experience, to which they can all later relate when they are processing the collected data. Repetition, in this case measurement of time and distance, improve students' skills. The comprehensive content of the talk among the students is characterised by a desire to make progress with the task. In this cumulative talk sequence, students strive to fulfil the most adjacent purposes, in this case, measuring the height from the window and the fall time of the two objects. When all students are focused on the same purpose and this purpose relates to the completion of a task, the talk becomes cumulative. Students do not need to ask each other follow-up questions since they all are well aware of what to do. From this cumulative conversation, we identify the following purposive moves (see Table 5).

Excerpt 2 – Exploratory talk during the activity analysis of results

The students have measured the height from the window to the ground and the fall time for both the ping-pong ball and the metal ball. They have just finished processing their data by inserting the measured time and distance in the formula $s = at^2/2$, and solving

Table 5. Coding scheme for a cumulative talk at a Cognitive level – Content.

Purposive moves	Definition	Example
Participation	Repeating and confirming each other's utterance can be seen as a means to be part of the ongoing work process.	George and Paul repeat and confirm each other's utterances (Lines 4–10).
Targeted work	All students seem to be well aware what data they are about to collect. No need of following questions.	All students are focused on measuring the height and the two objects' fall time (Lines 1–16).
Completion of the task	The students are all focused on gathering necessary data and completing the task at hand.	The students hurry to gather necessary data to be able to calculate the acceleration and complete the task (Lines 11–16).
Handling equipment	Learning or showing how to use equipment	George tells Tom how to use equipment (Lines 4–10).

it for acceleration *a*. In this transcript, the students are ascertaining the validity of their calculations.

Paul *initiates* the dialogue by asking for the result of the calculated acceleration (Line 1), followed by Tom and George who both *respond* at the same time (Lines 2–3).

(1) Paul: What did you get?
(2) Tom: [13 meter]
(3) George: [13,0]

Paul *follows up* by repeating the result and asks a *clarifying question* (Line 4).

(4) Paul: 13 meters! On the ping-pong ball?

George *confirms* the result and tries to *qualify* it.

(5) George: Yes, then the gravi uh gravity on this uh.

Tom is dissatisfied with George's statement and challenges it by making a comparison to the constant *g* (Line 6).

(6) Tom: 13? It must be less than 9?

George quickly responds by making a *contradiction* (Line 7).

(7) George: It shall not be less than 9! Then it goes faster.

Tom *accepts* George's response, which confirms his own statement (Lines 8–9)

(8) Tom: Yes it does, it seems to be right.
(9) George: It's correct!

John also *accepts* George's reasoning (Line 10). Tom starts to write down the result (Line 11).

(10) John: Yes.
(11) Tom: About 13.01, or what was it?

Paul, who has been listening, *extends* Tom's earlier *challenge* by *bringing in support* from an earlier activity (Line 12).

(12) Paul: Is it really less because it's under? Before we got 9.4 m/s. It should have been 9.83 and then [it's higher acceleration also]

George does not consider Paul's analysis. Instead, he asks for a final result (Line 13). Tom, on the other hand, implicitly accepts Paul's reasoning and returns to his initial opinion (Line 14).

(13) George: [but what do we get now then?]
(14) Tom: [It just can't be right]

George realises that he does not have the rest of the group with him. He stops and asks them to repeat what they just said (Line 15). Both Paul and Tom point out that the result cannot be right (Lines (16–17).

(15) George: [We get, we get.] What did you say now?
(16) Paul: [It can't be right!]
(17) Tom: [It can't be right!]

George *requests* Paul and Tom to *extend* their remarks (Line 18).

(18) George: Why?

Paul tries to strengthen his view by explaining what the consequences of their result would be (Lines 19–21). George finally *accepts* Paul's explanation and shifts the focus of the dialogue, by questioning the reasons for the incorrect answer (Line 22).

(19) Paul: It must be, if it's more the acceleration increase.
(20) John: Yes.
(21) Paul: The larger the number, the longer you will come on x.
(22) George: Ok, but what is wrong then? What formula is it? *a* but that is divided by two.

Linguistic level – Interaction: How do they speak to each other? The communication in this episode contains a lot of questions and answers. Some questions are simply requests for a result, but others ask for more clarification. In this exploratory talk sequence, the students consider and challenge each other's ideas, and they contribute by sharing relevant information and building on previous experiences. The students seek agreement through *discursive moves* such as *Qualifier,* which could be *Challenged* or *Accepted* and thereafter *Extended* by others (see Table 6).

Linguistic level – Content: What content is in focus and what topics are discussed? The content of the dialogue concerns the validity of the calculated value of acceleration. Tom reacts to the value of 13 m/s^2 as he compares it with a mentioned value of 9 (Line 6). Paul makes comparisons with values obtained from an earlier activity (Line 12). The students struggle and are trying to make sense of how to interpret the calculated value. The discussion in this transcript is formed by content moves found in (Table 7).

Cognitive level – Interaction: How the students interact through communication and make progress with the task. They progress through the task by inviting one another to speak and considering each other's statements. They propose alternative viewpoints demonstrating signs of supportive behaviour. A curiosity for knowledge dominates their debate, making the students sincerely reflect upon each other's different contributions to the discussion. By questioning their calculated answer, Paul and Tom indicate that they feel confident and secure within the group. This exploratory talk episode contains a lot of questions, implying a certain degree of uncertainty among the participants (see Table 8). It becomes clear that the speaker's credibility can affect the outcome of the conversation at a cognitive level, as George almost convinced Tom about the validity of the answers (Lines 7–9).

Cognitive level – Content: What purpose of the students does the talk-sequence express? This episode shows how students make progress at a cognitive level, through critical and constructive questioning of each other's ideas. Students proposed results (Lines 2–3), negated them (Line 4), offered alternative views and evaluated them (Line 6), as when Tom used prior knowledge to draw conclusions that offered a possible new learning

Table 6. Coding scheme for an exploratory talk at a Linguistic level – Interaction.

Discursive moves	Definition	Example
Qualifier	A student makes a statement for others to consider.	George begins to explain the implication of the result (Line 5).
Challenged	The qualifier is questioned and challenged.	Tom questions the result (Line 6).
Accepted	The qualifier is accepted.	Tom is temporarily convinced by George's explanation and agree (Line 8).
Extended	The qualifier is fully or partly accepted and then extended.	Paul extends Tom's earlier challenge (Line 12).

Table 7. Coding scheme for an exploratory talk at a Linguistic level – Content.

Content moves	Definition	Example
Evaluating results	Students compare their obtained results with a tabled value.	The students are comparing their results with the value of the gravitational acceleration constant (Lines 11–12).
Meaning of a physics concept	Students discuss how one variable is affected by others.	Students talk about how the changes in the results affect the fall time and the distance. Paul is the only one who mentions the term acceleration during the conversation (Lines 12 and 19).

Table 8. Coding scheme for an exploratory talk at a Cognitive level – Interaction.

Action moves	Definition	Example
Considering	Students thoroughly consider the meaning of what is being said.	Paul listens to what George and Tom are saying (Lines 2–11).
Questioning	Students questioning others' explanation of a concept.	Tom considers whether George's explanation is correct (Line 6).
Engaging	Students show engagement by asking following questions.	Paul is not convinced by George's explanation and asks a follow-up question (Line 12). Paul is really involved in the discussion, as he sincerely wants to understand the meaning of their result.

outcome. The transcript shows how the students struggle to categorise and embed new impressions and knowledge into their existing knowledge framework. In this exploratory talk transcript, we identified the following purposive moves (see Table 9).

Excerpt 3 – Disputational talk during the activity processing data

The following excerpt is taken from a laboratory station, where the task was to interpret and represent a written story in a position–time graph. The students in the groups were very committed to the task in this activity. They talk much more frequently, and argue using longer sentences compared to the other activities. They defined the zero point and they were analysing a person's movement from that position. The excerpt shows a dialogue where they debate whether the position /distance can be negative. Paul is convinced that the position (distance) never can be negative, but the other students argue the opposite. Since Paul is very persistent, the others gradually lessen their resistance to his argumentation (despite the fact that they never understand his perspective).
Tom initiates the dialogue by making an assertion (Line 1).

(1) Tom: But if it's zero it should be a curve like this also (Tom *draws in the air*) goes a bit up.

Paul immediately follows up with a counter assertion (Lines 2–3).

(2) Paul: No it won't!
(3) Paul: It must be like this!

Tom tries to strengthen his *assertion* by giving an example but gets interrupted by John who supports Tom's view but restates it in different terms (Lines 4–5).

(4) Tom: But if she walks towards the stove, then she goes
(5) John: Minus right?

George and Tom confirm John's contribution to the debate (Lines 6–7). Now all students have declared their point of view, which have divided them into two opposite sides, where Tom, John and George have the same opinion, but Paul thinks otherwise.

Table 9. Coding scheme for an exploratory talk at a Cognitive level – Content.

Purposive moves	Definition	Example
Conceptual understanding	Students try to understand the characteristics of a concept.	In this talk sequence, students try to understand the characteristics of acceleration as a concept (Lines 12–21).
Linking knowledge	Students value others' reasoning based on existing ideas.	Paul and eventually Tom, both consider George's explanation based on their existing knowledge (Lines 16–17).
Building on each other's ideas	Realise that the existing way of thinking may be wrong and embrace others ideas.	George finally realises that his reasoning does not hold and immediately seeks new ways to understand (Line 22).
Creating new knowledge	Students strive to understand the implications of their results, which allow them to create new knowledge.	Paul and Tom realise that their calculated value must be wrong and they together with George discuss possible explanations (Lines 16–22).

(6) George: It should be minus.
(7) Tom: Yes, so it is!
(8) Paul: No, it is not certain, because check the kitchen table, it will be about the same.
(9) Tom: Same as what?
(10) George: But she walks
(11) Tom: Yes, she walks back and then it will be minus.
(12) Paul: That isn't minus, is it?
(13) Tom: If she begins at the kitchen table.
(14) George: Yes, We start at the kitchen table.
(16) Tom: Yes.
(17) Paul: Yes, but she has gone outside.
(18) Tom: and then
(19) Paul: she goes back.
(20) Tom: Then it should be further down, below zero!
(21) Paul: No!
(22) Tom: Of course it will!
(23) George: Yeah, that's what I think.

Linguistic level – Interaction: How do they speak to each other? The dialogue continues back and forth between these two sides, with *discursive moves* like *Assertion* and *Counter assertions* (see Table 10), which categorise this dialogue as Disputational talk. The students do not fully consider each other's suggestions, but instead struggle to strengthen their individual point of view. The dialogue ends without the group reaching a common understanding, showing how difficult it is to sincerely consider, change and embrace new ways of thinking.

Linguistic level – Content: What content is in focus and what topics are discussed? Content moves. This dialogue describes how the students try to interpret and represent part of the story, written on the worksheet, to a position–time graph. The underlying issue that pervades this dialogue is the question about position and the existence of negative distance. The students do not explicitly use the word negative, but instead use the term

Table 10. Coding scheme for a disputational talk at a Linguistic level – Interaction.

Discursive moves	Definition	Example
Assertion	Students make assertion in an ongoing dialogue.	Tom makes an assertion by describing how the diagram should look like (Line 1).
Counter assertion	An assertion is followed by a counter assertion.	Paul immediately rejects Tom's assertion and describes his own point of view (Lines 2–3).

Table 11. Coding scheme for a disputational talk at a Linguistic level – Content.

Content moves	Definition	Example
Interpretation of a concept	Students argue for their personal view of a concept.	Students explain their views on the concept of motion and discuss whether a motion can be positive or minus (Lines 4–23).
Representation of a phenomena	Students debate different representations of a phenomenon.	Students discuss how to represent a person's motion in a diagram (Lines 1–3).

minus. The task causes the students to express and share their perception and understanding of how to represent motion in a diagram. In this case, the actual task becomes a scene for debate where the students argue their own opinion about the existence of a negative distance or position. Here, it is important to stress that none of the students ever uses the word distance; neither do they use the term position. In this excerpt, in this context, the debate concerns content moves found in (Table 11).

Cognitive level – Interaction: How the students interact through communication and make progress with the task. Among Tom, George and John, the conversation is positive as they show signs of supportive behaviour by confirming and elaborating on each other's statements and restating them in different terms (Lines 5–7). The conversation between Paul and the others, on the other hand, soon turns into a conflict where competition to be correct leads to contradictions. Paul stands fast in his view that the person in the story can never move in a negative direction, despite objections from the rest of the group. There is an obvious lack of negotiation space as both sides dismiss each other's arguments. During this dialogue, they clearly become irritated but still show mutual respect, since they drop the subject and construct the diagram according to Paul's view. But the unsolved issue affects the work when they later try to draw a diagram without negative values. This also causes problems for them when they try to answer the second question in the task – how to show that the person is back in the same position she started from. The interaction in this disputational talk excerpt is recognised by action moves summarised in (Table 12).

Cognitive level – Content: What purpose for the students does the talk-sequence express? George, John and Tom seem to have a feel for the difference between a position and travelled distance, but have problems expressing and conveying this in their argumentation with Paul, who indirectly claims that a distance never can be negative. George, John and Tom build on their prior knowledge as they confirm and extend each other's statements during the dialogue. Paul is not convinced by their arguments, which serves to strengthen his own understanding. The disputational dialogue in this excerpt strengthens the individual participant's own understanding regardless if it is right or wrong, and it is formed by purposive moves in (Table 13).

Table 12. Coding scheme for a disputational talk at a Linguistic level – Interaction.

Action moves	Definition	Example
Defending	Stays firm in existing beliefs, without sincerely considering others' opinions.	Paul rejects Tom's suggestion and insists on his own explanations (Lines 1–3).
Condescending	Students begin to be dismissive of each other when they do not get the expected response.	Paul stays firm in his belief, which upsets Tom and George, who answers Paul in a condescending manner (Lines 21–23).
Competing	Students' contradictions lead to competition in submitting a correct answer for the task.	Being right becomes more important for Paul and the other students than understanding (Lines 20–23).

Table 13. Coding scheme for a disputational talk at a Cognitive level – Content.

Purposive moves	Definition	Example
Reinforcing old knowledge	Students stand firm in their beliefs, reluctant to change, their existing knowledge is reinforced.	Paul is not convinced by their arguments, which serves to strengthen his own understanding (Lines 2–3).
Revealing knowledge	When students debate back and forth, their existing knowledge is exposed.	Tom and Paul have different opinions about the existence of a negative position (Lines 11–23).

Summary

The three excerpts were identified as cumulative, exploratory and disputational talk-types, based on Mercer's descriptions of talk-types. By developing the model further with regard to how the students make the moves in the process concerning interaction and content, we have identified content moves, action moves and purposive moves. A summary of descriptions of moves from the analysis above is given in (Table 14).

Discussion

The purpose of this study was to find a link between *how* students communicate and *what* students communicate about during laboratory work in physics, which would be useful first as a theoretical contribution for further research, and secondly as a pedagogical instrument for teachers in their effort of planning and designing effective laboratory work in the physics subject.

As a theoretical contribution, communicative moves during laboratory work in physics would be a way to identify empirically how specific laboratory activities have different potential strengths for learning outcomes regarding what both Tiberghien et al. (2001) and Llewellyn (2013) describe as possible appropriate objectives for laboratory work/inquiry. Practical work activities of very different kind can be analysed, despite the shallow verbal communication student sometimes show during such work.

As a pedagogical instrument, teachers might use the four questions to design appropriate activities, with some ideas of what will be functional for different purposes. By identifying interaction and content during activities, conclusions of how well the activity supports the teachers' purposes and students' aims for the activity can be identified from the four questions: (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 of the task? and (4) What student purposes does the talk-sequence express?

We have analysed student communication with rigour to find the links between interaction and content during laboratory work. The first research question focused on what students' interactions are communicated when different talk-types are in use. In our analysis, we can see that how students talk to each other at a cognitive level also affects how they act to make progress in the task. The identified action moves show that the character of such moves at a cognitive level seems to differ between the talk-types. The action moves identified in the cumulative transcript show how students work together side by side to make progress with the task. These cumulative action moves all describe interactions directed from one person to someone else, for example, *instructing* and *informing*. The disputational action moves identified also refer to how students act towards each other, but in this case, their communication seems to prevent them from progressing

Table 14. Moves for interaction and content found in the three episodes. Suggested model for empirical analyses of talk during laboratory work.

	Interaction			Content		
Talk-types	Disputational talk	Cumulative talk	Exploratory talk	Disputational talk	Cumulative talk	Exploratory talk
Linguistic level	Discursive moves:			Content moves:		
	How do they speak to each other?			What content is in focus and what topics are discussed?		
	Assertion	Request for actions	Qualifier	Interpretation of a concept	Implementation	Evaluating results
	Counter assertions	Confirmations	Challenged	Representation of a phenomena	Use of equipment	Meaning of a physics concept
		Repetition	Accepted		Taking notes	
			Extended			
Cognitive level	Action moves:			Purposive moves:		
	How do the students act and make progress of the task?			What student purposes does the talk-sequence express?		
	Defending	Declaring	Considering	Reinforcing old knowledge	Participation	Linking knowledge
	Condescending	Instructing	Questioning	Revealing knowledge	Targeted work	Conceptual understanding
	Competing	Requesting	Engaging		Completion of the task	Building on each other's ideas
		Informing			Handling equipment	Creating new knowledge

with the task. Students act more defending as they take a clear stand in the issue being discussed. The exploratory action moves identified concern talk related to person speaking, thus describing how a single individual acts to progress with the task.

The second research question focused on what content is being communicated during laboratory work, when different talk-types are in use at both a linguistic and cognitive level.

We were able to identify and distinguish both content and purposive moves in the three transcripts. In the cumulative talk sequence, students content moves at a linguistic level concerns what they are about to do and how they should do it, for example, measuring a height, clocking a falling object. Students do not ask each other follow-up questions, indicating that they are aware of what to do. In the exploratory transcript, students ask a lot of questions as they try to obtain a deeper understanding of the concept of acceleration. Due to their lack of a physics language, they express and discuss their perceptions of acceleration using language from everyday life. The content in the exploratory transcript revolves around physics concepts. In the disputational transcript, students start by discussing their interpretation and representation of the concept velocity, but the conversation soon shifts to instead focus on who is right and who is wrong. The identified disputational content moves refer to physics concepts and conceptual understanding, similar to the identified exploratory action moves. This does not imply that disputational content moves always and solely refer to conceptual understanding, but could probably also be linked to physical actions in another setting and context.

The identified purposive moves are differentiated more clearly according to talk-type than the content moves. During the cumulative talk, students strive to fulfil the most adjacent purposes. When the entire group is focused on the same purpose, which is related to the completion of a task, the talk becomes cumulative. In the exploratory transcript, we see how students use prior knowledge to draw conclusions that offer a possible new learning outcome. The transcript coded as exploratory talk shows how the students jointly struggle to categorise and embed new impressions into their existing framework of physics knowledge. In the disputational talk sequence, students' existing physics knowledge seems to be a limitation for their intense discussion to evolve into new understanding. Most likely, the students did not possess knowledge about position and motion in a physics context, as none of them used these concepts in his arguments.

In the cumulative talk, purposive moves differ, in that they are expressed as talk and are aimed at helping the group to progress with the task, whereas purposive moves in both the exploratory and disputational talk sequences are expressed through talk as thought.

The purposive moves allow them to link knowledge and build conceptual understanding. This is consistent with Scott, Mortimer, and Ametller (2011) view, who mean that learning involves integrating the formalised scientific view with existing ideas. Learning involves making links to differentiate the everyday views from the scientific way (Scott et al., 2011). The purposive moves are valuable in the sense that they represent information concerning what the teacher actually assigned the students to do. It is also important to stress that the definition and use of moves in the dialogues are an innovation that must continue to demonstrate its strengths through additional validations processes. The purposive moves expressed by students would most likely diverge from the purpose set by the teacher. In that respect, discourse analysis in terms of content can be a viable approach to assess the effectiveness of the laboratory task. We consider these purposive moves as waypoints marking where students' conversations take a new direction. These changes of direction are important, as they can signify change of talk-type. The identified moves in the four categories further clarify existing differences among the three talks. The relation between students' communicative moves at a linguistic level and outcomes of their action at cognitive level appears to be strongly correlated. Students' practical progression is guided by cumulative talk and students' conceptual progression are mainly guided through exploratory talk aroused from cumulative talk sequences.

The validity, based on how well we are able to measure the answers to our research questions, is strengthened by the fact that we developed our method of operation from a framework that has already been confirmed by the research community. In this study, we apply this method in a situation where we want to more deeply explore a process that partly can be analysed by accepted procedures in the content analysis. Even so, the presented analytical framework with our moves should be considered tentative until it is applied on a more comprehensive data collection. The expressed content and purposive moves are not to be seen as generally occurring moves for a particular talk-type, but are instead connected to the content specifically associated with the task at hand. This makes it easier to more closely follow a group of students and investigate how they make progress not only through interaction, but also conceptually. We intend to do so by applying the analytical framework to another video-recorded laboratory work lesson.

We agree with Mercer (2004) that exploratory talk is the most valuable form of educational conversation in the sense that students challenge, accept and extend each other's statements and strive for consensus at a linguistic level, thus causing students to evaluate old knowledge and make links to new knowledge at a cognitive level. Based on our study, we argue that students must be offered time and space for discussion during their laboratory work, not only to manage the critical parts of completing the task, but also to go beyond the task and create new knowledge. Knowledge about the outcomes of the different talk-types is of utmost importance for teachers when designing appropriate laboratory work sessions.

The cumulative talk sequences are shallower on a cognitive level compared to the exploratory talk sequences, but during laboratory work, cumulative talk seems to be used as a compass enabling students to use action moves such as instructing, seeking and giving information, thus keeping the students on track and guiding them forward. Our interpretation is that these cumulative talk sequences in a laboratory context can act as a foundation and reference for students in their forthcoming exploratory talk dialogues. However, for this to occur, students must be given time and opportunity to consider and reflect upon their work. Maloney and Simon (2006) suggest that science education should include opportunities for developing reasoning through the use of small group activities. Based on our results, we agree with these authors, and claim that laboratory work can act as an arena for joint consideration and reflection. For this to happen, students in general and teachers in particular need to develop the awareness and skills to conduct effective group discussions, as also concluded by Bennett et al. (2010). Training students in argumentation also improves their investigation skills, according to Kind, Kind, Hofstein, and Wilson (2011). We mean that such developing of reasoning should also occur naturally and within a context such as laboratory work, preventing laboratory work from becoming yet only another isolated event. Disputational talks as a way to organise debates have functioned as a pedagogical tool when teaching students argumentation. In our study, scientific argumentation is important, but so is the ability to argue based on values and experiences. What is more, this area of research now emphasises the way that exploratory and consensus-related talk may contribute to collaborative meaning-making. Dialogic argumentation or collaborative argumentation seems to cover part of the same phenomena, even if the product focuses on written arguments (Evagorou & Osborne, 2013). Different types of communication seem to allow students to make moves that both deepen their understanding of how to proceed with the task and how to grasp the physics content. Through communication, students give themselves experiences of how laboratory work can enhance their competence to collaborate in a scientific environment with complex practical and theoretical questions to solve quickly.

The result shows that the different talk-types promote different purposes in this physics laboratory work context. The laboratory work should therefore be designed accordingly to accommodate different types of exercises that also stimulate different types of talk. One activity is a practical part of an investigation where students use cumulative talk to progress. An other activity where students are given time for reflection and opportunity to deepen their conceptual understanding through exploratory talk. Disputational talk can also be productive if it drives students to explain their contemporary view of physics and reason based on their conceptual understanding.

We find that the key question for physics education for the future is how to teach core physics in a stimulating learning environment for students aged 15–18 years. We envision a learning environment where they feel free to talk using both their everyday life language, but where they are also encouraged to express themselves using physics terms in relevant activities. In this study, we wanted to further investigate how students' communication is structured during the process of laboratory work in physics. Deeper knowledge about students' communication and links to outcomes of their action is important regarding the debate about the effectiveness and role of laboratory work.

Implications for physics education and for research

Generalisation

The context and the amount of data this qualitative study's results are deduced from are too narrow to make broader claims than case-to-case generalisation (Firestone, 1993). Even so, the study shows that a discoursive approach, searching for moves, can be a fruitful approach to investigate interaction and content of students' communication at different levels. The structure of the model presented is static in terms of the differentiation between *how* and *what* students talk about, but should be considered dynamic in terms of identified moves under the four main categories. Content moves are closely linked to the context of students' work and can be expected to differ in another setting. Except from the limitation to how and what students are communicating about during a group activity, the degree of generalisability in the presented analytical process is for prospective user to decide.

- We believe that insight about our findings can help experienced physics teachers to design effective laboratory work modules. They can also better predict students' use of time and to a higher extent promote students in discussions concerning the meaning of physics concepts and different procedures, instead of just talking about what to do. Many cookbook-like tasks encourage cumulative talks. Teachers and students need to focus more on the why-questions in laboratory activities to further provide opportunities for exploratory talks.

- Our analysis shows how easily a conversation that starts as an exploratory talk can turn into a disputational talk. In conversations of such disputational character, students need guidance from their teacher to overcome difficulties and turn them into new knowledge.
- The cumulative talk consists of purposive moves where the students describe what they are doing or what they are about to do. We believe that teachers should also include activities promoting these cumulative conversations but without becoming dominant, as such talk allows students to become accustomed to the process of a scientific investigation.
- This new approach of analysing not only how students talk and interact, but also what they talk about and what purposes they express, must be researched even more and developed in other contexts. For example, a next step could be to follow individual students during a complete laboratory session and investigate what content and purposive moves are taken and to what extent these purposive moves are fulfilled. Such a study would add a new piece to the puzzle concerning the effectiveness of laboratory work.

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