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Learning Physics in Small-Group Discussions – Three Examples

Sylvia Benckert and Sune Pettersson
Umeå University, Umeå, SWEDEN

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This article reports on an investigation of students learning of physics during group discussions around context-rich problems in introductory physics courses at university level. We present the results from video recordings of student groups solving three different problems. We found that group discussions around physics problems can lead to stimulating and learning discussions of physics but we also observed situations when the discussions did not work well. Misunderstandings of physics concepts reported in the literature emerge in the discussions now and then but the students also detect new 'problems'. In the discussions most misunderstandings and problems are treated and solved either by the students themselves or by the students together with the teacher. Factors that stimulate a good discussion are engaging problems and a teacher at hand to answer questions and to discuss with the students. Factors that prevent a fruitful discussion are too little knowledge of the actual physics among the students and bad functioning of the groups.

Keywords: Context-rich Problems, Group Discussion, Physics Education, Problem Solving

BACKGROUND

Many physics students do not find physics interesting and many of them pass physics courses even at university level without an acceptable conceptual understanding of physics. Small-group learning seems to promote both interest and understanding of physics concepts and principles. Springer, Stanne, and Donovan (1999), for example, showed in a meta-analysis that students in undergraduate courses in science, mathematics, engineering and technology who learn in small groups in general show a greater academic achievement and express more favourable attitudes toward learning than students that have been taught in a more traditional setting.

In a socio-cultural perspective meaning making is seen as a dialogic process (Barnes & Todd 1995; Lemke 1990; Mortimer & Scott 2003). We agree with the philosophy of learning expressed by Barnes and Todd (1995, p. 10) that one of the most important ways of working on understanding is through talk. When students talk with each other they rephrase their own ideas, obtain another perspective from their peers and can eventually reach an improved understanding. Barnes and Todd introduce the notion of "exploratory talk" when speakers think aloud, a talk that includes hesitations and changes of directions, assertions and questions, self-monitoring and reflexivity. This way of talking often occurs in group discussions and so these could be promising milieus for learning.

Correspondence to: Sylvia Benckert, Senior Lecturer
Department of Physics, Umeå University
SE-901 87 Umeå, Sweden
E-mail: sylvia.benckert@physics.umu.se

Group discussions in physics

Group discussions around context-rich problems in physics were introduced at the University of Minnesota (Heller, Keith & Anderson 1992; Heller & Hollabaugh 1992). The context-rich problems are written as short stories about real objects or events including a reason for calculating a specific quantity (Heller & Hollabaugh 1992). The student is the principal figure in the story and the personal pronoun "you" is used throughout the problem. The problem statement does not always specify the unknown variable. More information may be available than is needed to solve the problem or some necessary information may be missing. The students solved these problems in cooperative groups. In a

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review of research on small group learning, Cohen (1994) found that small group learning can be productive for conceptual learning if certain conditions are fulfilled. The most important of these conditions is that the task is a real group task. The context-rich problems seem to fulfil these requirements. Heller et al. (1992) also found that in well-functioning cooperative groups a better problem solution emerged than was achieved by individuals working alone and the instructional approach improved the problem-solving performance of students at all ability levels.

Advice for instruction of cooperative groups is given by Johnson, Johnson and Smith (1998) and much of this advice is applied in small group-learning in physics by Heller and Hollabaugh (1992). They found that groups with three students of mixed abilities functioned well together. If a group consisted of two students, they often did not produce enough good ideas to solve the problem and if the group consisted of four students, one student was invariably left out of the problem-solving process. Also in three-member groups there could be problems of dominance and conflict. To avoid these problems they used rotating roles as Manager, who keeps the group on task, as Sceptic, who helps the group to avoid quick agreement and asks questions that will lead to understanding and as Checker/Recorder who checks for consensus and writes down the group solution.

Gautreau and Novembsky (1997) used small group learning in introductory physic courses at the university. They let students work in groups of three or four after a short lecture. They describe this as a first teaching by the lecturer who introduces concepts followed by a second teaching where students in small groups digest initially brittle ideas into workable knowledge that students own themselves. Molly Johnson (2001) introduced problem solving in small groups in introductory courses in physics at university level. Students worked in groups of two to four and the group members took on roles as writer, leader and sceptic. The problems were similar to those in textbooks focusing on conceptual and problem solving skills. Johnson presents the implementation and difficulties with this approach. She notes that the students during the group discussions raise questions that have been identified in the literature as important difficulties for students, often overlooked by texts and instructors. Enghag, Gustafsson and Jonsson (2007) found that students reach consensus in group discussions using exploratory talk and that individual questions are formulated in the process of meaning making and that these questions recur during the conversations.

Booth and James (2001) and Samiullah (1995) investigated the effects of student-student interaction on learning physics at university level. They found that the cooperative learning did not have any effect on the students' performance on test afterwards. These studies are of the type "black box approaches" in which they compare a cooperative method to a traditional teaching method on outcome measures only.

Problem solving in physics

Problem solving is seen to be an essential part of physics learning. Traditional end-of-chapter problems are, however, often criticized because students have a tendency, when they solve these problems, to just grab an equation and plug in numbers. Why students act in this way is explained by Larkin, McDermott, Simon and Simon (1980). Students often start with the goal of the problem and work backwards. They identify the goal as finding a specific numerical value and the most reasonable and efficient way to reach that goal is to find an equation. This behaviour is understandable but it does not enhance learning in physics.

Maloney (1994) gives an overview of research on problem solving in physics. He finds that several studies argue that standard problems are not effective tools for helping students learn relevant concepts and principles of physics. Is it possible for students to develop solid, thorough declarative knowledge bases before they are given problems to solve or does solid understanding require that they attempt to apply the knowledge from the domain? Maloney finds studies that imply that working with problem examples is an important part of learning declarative knowledge, but other studies imply that students need to have a solid knowledge base to be able to solve problems effectively. Maloney also states that many studies show that making students adopt a definite problem-solving strategy results in better problem solving. He also concludes that if we expect students to learn concepts and principles we may need to alter the form of the assigned problems. There are different suggestions of the type of tasks to be used to replace standard problems and one of the suggestions is context-rich problems.

Heller et al. (1992) were interested in what way problem solving was best learned and formulated a problem-solving strategy which included a detailed five-step procedure to solve real-world context-rich physics problems. The first step is to make a translation of the problem statement into a visual and verbal understanding of the problem situation. The second step requires the students to use their understanding of physics concepts and principles to analyze the problem in physical terms. The third step is to plan the solution, the fourth step to execute the plan, and the fifth step to evaluate the reasonableness of their answer. Heller et al. say that they have reason to believe that teaching this problem-solving strategy to solve context-rich problems enhances students' conceptual understanding.

Huffman (1997) investigated if students in high school who were taught to use an explicit problem-solving strategy exhibited greater improvement in problem-solving performance and conceptual understanding of physics than students who were taught to use a textbook problem-solving strategy. The results indicated that the explicit problem-solving instruction helped improve the quality and completeness of students' problem representations but it did not seem to significantly affect students' understanding of concepts. Leonard, Dufresne and Mestre (1996) on the other hand introduced qualitative problem-solving strategies to highlight the role of conceptual knowledge and they found that these strategies were valuable for focusing students' attention on the role conceptual knowledge plays in solving problems.

Learning physics concepts

Findings from many studies show that students come to science courses with knowledge and beliefs about the phenomena and concepts to be taught and in many cases students' ideas are not in accordance with science views. Commonsense beliefs about motion and force are for example incompatible with Newtonian concepts in most respects and traditional physics instruction produces little change in these beliefs (Halloun & Hestenes, 1985; Hake, 1998). There are many studies identifying and analysing students' difficulties in different areas of physics. McDermott and Redish (1999) give an overview of this type of research.

Many researchers have seen students' difficulties with physics phenomena as rather strongly held misconceptions or alternative conceptions that have to be addressed by instruction. The idea of strongly held misconceptions, however, has also been challenged. It can be argued that students do not have coherent frameworks and that there is a variation of students' reasoning across different contexts. Misconceptions could appear as an act of construction of knowledge. DiSessa (1993) suggested that students' intuitive physics knowledge is built by explanatory abstractions of experiences in the day-to-day physical world called phenomenological primitives. "Closer means stronger" and "force as a mover" are examples of such p-prims. One conclusion from this work is that the intuitive knowledge does not need to be replaced but should be developed and refined. Hammer (1996) analysed how a teacher may perceive students' participation from the two perspectives, misconceptions and p-prims, and he found both valuable. The misconceptions perspective was more valuable to help students become aware of their reasoning, while the p-prim perspective motivated the teacher to discuss and refine definitions and students' ideas. Hammer also points out that the context sensitivity of students' discussions was easier to understand from the p-prim perspective than from the misconception perspective.

As Driver, Asoko, Leach, Mortimer and Scott (1994) write, the constructivist position is shared by a wide range of different research traditions related to science education. One tradition focuses on individual construction of meanings while another tradition describes knowledge construction as a social construction of knowledge. Leach and Scott (2003) present a view of science learning drawing on both socio-cultural and individual views. They conclude that learners must reorganise and reconstruct the talk and activities on the social plane and so Vygotskian theory through the process of internalisation brings together social and individual views. Even if Leach and Scott see limitations in the individual views of learning, they think that the so-called 'alternative conceptions literature' does offer useful resources for those interested in improving science education.

An important background when studying students' problem solving is identified conceptual and reasoning difficulties that students encounter. In our study students solve one problem in special relativity and there are a few studies of problems that students encounter in their study of relativity. Posner, Strike, Hewson and Gertzog (1982) in a classic study of conceptual change interviewed students and physics instructors about problems in special relativity. The central metaphysical belief that contrasts special relativity with classical mechanics is its rejection of absolute space and time. Posner et al. found that if a student requires objects to have fixed properties such as lengths, he or she may explain length contraction by saying that the rod does not shrink; it is just a perceptual problem. Hewson (1982) interviewed a graduate student as a case study about the propositions that moving clocks runs slow and that moving rods shrink and this student also saw length contraction as a question of perception. Scherr, Shaffer and Vokos (2001) report on an investigation of student understanding of time in special relativity. They found that students most often do not spontaneously recognize that simultaneity is relative. Frames of reference are important in special relativity and Panse, Ramadas and Kumar (1994) investigated how students handled these conceptual tools.

The second group discussion that we report deals with sound. There seems to be very few studies of students' acquisition of concepts related to sound. Published studies focus on students' thoughts about factors affecting the sound velocity (Linder, 1993) and about a common misconception that sound waves have object-like properties (Wittmann, Steinberg, & Redish, 2003).

The third group discussion is about a problem in mechanics where knowledge of energy of rotating rigid bodies and moment of inertia is necessary. There are lot of studies of problems that students encounter when studying mechanics, but we have not found any studies dealing with rotating bodies.

Research questions

We have for some years, inspired by the work at the University of Minnesota, used group discussions around context-rich problems in the first courses in physics at university level. We introduced group discussions because we saw a need for more discussions about physics concepts and principles but also about problem solving. From the research literature we find that group discussions could be a promising milieu for learning physics. Most studies of group discussions are, however, from secondary school and this is especially true for those which are not "black box approaches". Therefore it is a need for more in-depth studies of group discussions at university level.

We want to find answers to the following questions:

- How do students discuss and solve physics problems in group discussions?
- What kinds of problems with physics concepts and principles do the students encounter?
- What does group communication mean for the problem solving to be successful?

RESEARCH CONTEXT AND METHOD

We introduced group discussions around context-rich problems in our introductory physics courses at university level seven years ago and have used this teaching method since then. In our group discussions, students have about two hours to solve one or two context-rich problems and the students are supposed to solve the problems within the allocated time. We introduce a problem-solving strategy similar to the one described by Heller et al. (1992). After some of the group discussions the groups were obliged to hand in a solution of the problem in which all steps should be well motivated and should follow the steps in the problem-solving strategy. These problem solutions were then given back to the students with comments. We have also found that groups of three students are ideal in our group discussions. We try not to have just one female student in a group. Sometimes this can still be the case when groups are rearranged because some students are missing. The group roles, Manager, Sceptic and Checker/Recorder are introduced at the start of a course. We have not stressed the use of group roles but we have found it useful to start with. During the group discussions the teacher is present the whole time and intervenes when necessary. The groups are free to ask the teacher for help and advice whenever they need.

This study was done during two introductory physics courses, Mechanics, relativity and experimental methods, and Electricity and waves. The class consisted of 16 students, 10 aiming for a major in physics, 3 pre-service teachers and 3 other students. The students worked with just one course at a time, which is the traditional way of studies at Swedish universities. In the courses there were lectures, laboratory work and group discussions and the students had lectures almost every day and group discussions about two times a week.

We constructed groups with three students and in some cases four students. We formed the groups so that they were composed of students of different abilities as shown by the results of a FCI-test (Hestenes, Wells & Swackhamer, 1992) given to the students at the beginning of the Mechanics course. The ideal was to keep the assigned groups during the whole course, but when one or more students were absent, new groups were formed temporarily. Regrouping of the students was made once during the two courses and then the teachers used their personal knowledge of the students to guide the formation of new groups.

In this article we report the results from three group-discussion occasions. We video recorded two study groups at each of these three occasions. These three group discussions were in some ways different from each other. In the first group all the students were active and very enthusiastic about a problem in special relativity. The second group discussion dealt with a more qualitative problem. The second problem was included in order to study if the discussions would be different for a qualitative problem compared with more ordinary context-rich problems. The teacher had in previous classes had group discussions around questions such as: "Explain the reasons for the rainbow". He had then observed that the group discussions tended to be rather shallow with these "Explain questions" and the questions did not seem to engage the students as much as the context-rich problems did. In the third group discussion the groups did not function so well. This discussion dealt with a problem in mechanics with rotational energy.

The students filled in a small questionnaire of Likert-type format at the end of the group-discussion sessions. The students answered three questions: How interesting did you find the problem? How difficult did you find the problem? How much have you learned through solving this problem? They could choose six different answers ranging from for example "Not at all interesting" to "Very interesting".

At the beginning of the group-discussion session we selected groups for video recording and the members of the groups all had to agree to be videotaped. We wanted to keep an authentic milieu for the group discussions that we recorded so we brought the equipment to the location that the groups chose for their work. A camera was mounted in front of each group and an external microphone was placed on the table in the middle of the group. It took some time before the equipment was set up and the camera rolling so the first minutes of the discussions were usually not caught on tape. The tapings of the group discussions on special relativity and on rotational energy all took place in the lecture room where the other groups were working. This led sometimes to disturbing noise from neighbouring groups that made it difficult to hear some utterances when we analyzed the films. One of the recordings of the second group discussion was made in the lecture room and the other took place outside the lecture room at a relatively quiet place found by the students themselves.

We started the analyses by looking through the video tapes from the group discussions and noted what happened. We then looked through the tapes several times, transcribed the records, and analysed the documented group talk. By studying the students' comments, questions and interplay we tried to achieve a picture of the students' lines of reasoning and their problem-solving process. We especially looked at the students' handling of important physics concepts and principles in their problem solving and if they showed some alternative conceptions or misunderstandings. We also looked at the group interaction by noting the distribution of talk among the group members.

RESULTS: LEARNING OF PHYSICS – THREE EXAMPLES

The three examples are group discussions around a problem in special relativity, a more qualitative problem about sound waves and a problem in mechanics and rotational energy. From the questionnaires given to the students after each group-discussion we found that the problem in special relativity was seen as the most interesting, the most difficult and the problem from which they learnt the most. The other two problems were judged to be rather interesting and difficult but less so than the problem in relativity. The students also said that they learned physics from these two problems but less so than from the problem in relativity.

Group-discussion around a problem in special relativity

Before this group discussion the students had attended one lecture on Time dilation and length contraction and in the morning the same day a lecture on the Lorentz transformation. The teacher's purpose for including a group discussion with this problem was to give the students a possibility to discuss and realize that it is not enough to know the length-contraction formula, they also have to be able to use the Lorentz transformation and they must be aware that the simultaneity is relative. We video recorded two groups when they tried to solve the problem given below. In one group there were four male students and in the other three female students.

A test of length contraction?

Two of your friends decided, when they travelled by train, to try to determine the length contraction of a very rapid train. They planned to sit at the two ends of a 100 m-long train with their watches properly synchronised. At the time $t = 0$ each of them should drop a bag through the window. These bags should act as markers. When the train stopped at the next station they could go back and measure the distance between the bags. Shouldn't the distance between the bags then be the length of the train as measured by observers on the ground? Your friends ask you about this because they know that you are very good at Lorentz transformations. Your friends tell you that they suppose that the velocity of the train is 0.7 c and that you can neglect the time for the bags to fall to the ground. We calculated the distance between the bags to 71 m, they say. Is this right?

In the group with three female students (Anne, Susan and Tanya) Tanya starts the discussion: "This seems to be fun." The first step in their problem solution is to try to understand what the problem is about. Then Anne tries to do as in another problem, they have solved, with a car driving through a garage which is open in both ends, and they stumble on a dilemma. Anne uses the formula for length contraction and calculates the train to be 71 m. Tanya is not quite convinced that this is the right way to start.

Tanya: Is this really applicable here?

Susan: If you look at the train, you see the train going by as being shorter.

Tanya: But the thing is that you don't do that. You go back and measure the distance.

Is the train 100 m or 71 m? Anne makes their dilemma clearer.

Anne: Shouldn't the distance between the bags be the length of the train that is measured by the observers on the ground? The train goes by with 0.7 c. And then they look at the train and think it is 71 m. And I think that the bags should end up 100 m from each other because the train is 100 m, but if you look at it, it is 71 m.

Then they go on and discuss this dilemma, compare with other problems and expound the problem with other examples. They once again compare with the garage problem and Tanya wonders if their dilemma could be explained if the length contraction could be seen as an optical illusion.

Tanya: Optical illusion. I know I shouldn't call it an optical illusion, but I do so. The optical illusion is still there when the car has stopped; otherwise the optical illusion wouldn't be there when the bags have stopped because they go straight down. But perhaps that is just what I think.

Susan: That is tricky. When they land they have 0.7 c. What is happening just when they land?

They go on and discuss what happens when the bags fall down and if the distance between the bags is 100 m or 71 m.

Anne: It has to be the same way from the other side. It is the same thing from the train as from the ground.

Tanya: But I can absolutely not explain why it should be 100 m between them. I don't know what to call the 71 m, because in reality the train is 100 m.

Anne: In reality and in reality? That is tricky.

Tanya: I think.. I think it is peculiar. I want to see the contraction more as an optical illusion.

Here the idea of length contraction as an optical illusion turns up again. Then Susan discusses what happens when you go by the train and you see two stones on the ground 100 m from each other. She concludes that you see the distance between the stones as 71 m from the train. So she finds that the length contraction is the same seen from the train as seen from the ground. They go on and make up more examples that resemble the actual problem.

Eventually time and simultaneity comes into the discussion. The word simultaneity comes into the discussion for the first time when Anne says: "We could just answer that there is no simultaneity." The discussion goes on. Susan points to something in her notes and Anne answers that she thinks that time shouldn't be of any importance. "Shouldn't it?" Tanya asks and in a while Anne has a suggestion. Probably she has thought of the importance of time and also heard something from a discussion between the teacher and some other group.

Anne: I think, as I heard now and I have been sitting here and thinking. When we look at them from the ground, they don't do it at the same time (Drop the bags.).

Tanya: Don't they?

Anne: I don't think so.

Tanya: Will we first see one of them, poff, and then the other, poff?

Anne: Yes.

Tanya: But which comes first?

Anne: I think it is…

Tanya: First one of them, poff, and then the other, poff. Which comes first? Because if the one at the back comes first, then it could very well be 100 m between them.

Susan and Tanya then discuss what it means that the bags are not dropped at the same time and Tanya explains for Susan that if the person at the end of the train drops his bag first the distance between the bags on the ground could be 100 m. If the person at the front of the train drops his bag first the distance will be shorter. They go on and discuss what this means and if the distance between the bags might be 100 m.

So they are able to solve the problem. Ann writes down the Lorentz transformation for time and they calculate the time t when the bag at the front of the train is dropped. They calculate the distance travelled by the train since the bag at the end of the train was dropped. They hope this distance will be 29 m, so that the distance between the bags should be 100 m. The result they arrive at is however 68 m so the distance between the bags must be 139 m. They discuss the result with the teacher and they then also realize that the distance between the bags as measured from the train is still 100 m and that a distance 139 m at the ground is seen as 100 m from the train. They end the discussion by reflecting on their work.

Anne: On the train they still think that the distance is 100 m.

Tanya: Everything that we discussed was very logical.---

Susan: It was a very good problem. It was fun really.

All three students in this group participated in the discussion to the same extent. They started to discuss what the problem was about. They compared with another problem and they constructed new examples to illustrate the problem. The discussion eventually led them to the solution of the problem. They listened to each other and asked questions, when they didn't understand.

The second group discussing this problem went on in about the same way as the first group. They started to discuss length contraction and how this phenomenon should be interpreted. Also in this group one student suggested that the length contraction could be explained as an optical illusion. This group asked the teacher for help several times and they needed this help to realize that the bags were not dropped at the same time as seen from the ground. Then they concluded that the person at the end of the train must drop his bag first and they could calculate the distance between the bags on the ground.

In this group as in the first group all the students seemed to enjoy the discussion but two of the students talked more than the other two and sometimes there was a discussion going on in two subgroups. At some occasions one of the students seemed to dominate the discussion and he was also the group member who most eagerly wanted to hear the explanations from the teacher.

The students in both groups gradually evolved their understanding. They compared with problems they had solved earlier and they made up their own problems to clarify the situation. They discussed back and forth. The second group got explanations from the teacher several times and they then repeated with their own words, what the teacher had said.

In this problem the students were lead by the problem formulation to discuss length contraction and the students thoroughly investigated what length contraction might be before they could solve the problem. Tanya wanted to call the length contraction an optical illusion and so did a student in the second group. This misunderstanding is in accordance with the results found by Hewson (1982). From these group discussions we can, however, see that the view of length contraction as a form of perception is not a firm misunderstanding. It is rather a suggestion when the students tried to find an explanation to their peculiar results. Even if this is not really misunderstandings it is useful for the teacher to know that the students discuss in this way and it could be valuable to discuss it in class after the group discussion to make the students aware of the problems with such an interpretation.

Scherr et al. (2001) report on an investigation of student understanding of time in special relativity. They found that students most often do not spontaneously recognize that simultaneity is relative and from the beginning our students did not realize this either. They needed a lot of discussion and for one group help from the teacher to really understand and accept it. Of course these students have in the lecture heard that the simultaneity is relative and they have also in lectures been told that length contraction is a consequence of the fact that the simultaneity is relative, but this is not the same thing as understanding it and being able to use the knowledge in problem solving. This group discussion shows that students need to discuss such phenomena at length to really understand what it is about. As there are many aspects of special relativity that are counterintuitive it seems to be especially important for the students to be able during discussions to find out all contradictions in their reasoning.

The discussions in the groups also indicate that the students can have problem understanding what a reference system is. One student said, "They leave this system and the earth is the other system, isn't it?" This is a misunderstanding also described by Panse et al. (1994). In this group discussion it can be discussed if this really is a misunderstanding or if the student just did not express himself in a correct physical manner. The group did not discuss the question; it was just one student that talked in this way. In this case it could also be valuable to discuss in a lecture after the group discussion if it is possible to fall from one reference system to another.

The problem formulation led the students to interesting discussions. When the students tried to solve the problem, lead by the problem formulation, they used their knowledge of length contraction and calculated the distance between the bags to be 71 m, but at the same time they thought that the distance ought to be 100 m. It became a paradox for them and it was very interesting for them to go on and discuss the problem. We have in another study (Benckert, Pettersson, Aasa, Johansson & Norman 2005) also found that students find it interesting to solve problems where they have to determine if something is true or not. This is more interesting than to just be asked to calculate for example a certain velocity or distance. The formulation of the problem with the question "Is this right?" may be another factor, besides the paradox, that makes this problem interesting for the students and makes it a real group problem.

The helium problem

We studied two groups that discussed why the voice of people changes if they inhale helium gas. This was a part of the combined course in electricity and waves. Before this group discussion the students had attended three lectures on mechanical waves, one of these, about sound waves and resonance, was given the same morning as the group discussion.

> *Changing the pitch by inhaling helium*
>
> If you inhale helium gas you will get a completely different voice. What is the reason for this and how will the pitch change? Note that it can be dangerous to inhale large quantities of helium gas. The lungs will normally prevent suffocation by detecting a surplus of carbon dioxide, but with helium gas you don't experience any suffocation discomfort.

The teacher had expected the students to discuss which frequencies that would dominate by comparing with standing waves in a pipe. Since the size of the organs of speech is not changed by inhaling helium the standing waves must have the same wavelength. The relation between the speed of sound, v, the frequency, f, and the wavelength, λ, is given by $v = f \cdot \lambda$ for all periodic waves. By comparing the speed of sound for air and helium the students were supposed to draw the conclusion that standing waves in helium will correspond to higher frequencies than in the case with air.

We video recorded two groups when they tried to solve the helium problem. The first group consisted of four men, David, Ron, Ken and Bill. The second group consisted of three men, Charlie, John and Ben. Both groups start off by looking for formulas with which they can calculate the sound velocity in helium gas. The teacher intervenes and shows that they can find the sound velocity for helium gas in their textbooks. He intervenes at an early stage since he has experience from the year before that students tried to find ways to calculate the velocity instead of finding a tabulated value. The sound velocity of helium is tabulated to 999 m/s which is about three times higher than the sound velocity in air, 340 m/s. After the groups have found the value of the sound velocity of helium they started to discuss the reason for the higher pitch of the person's voice. Both groups start off with the assumption that the vocal cords produce a certain frequency regardless of which gas that is surrounding them. This assumption is taken for granted and is never questioned until the teacher intervenes. This leads to much discussion about how the frequency changes when the sound goes from one medium to another.

The teacher approaches the first group and asks them to tell him what tey have found out.

Bill: When the sound is created in the throat then…then the vibrations in the vocal cords are transmitted to the helium gas and these vibrations must be…
David: …the same.
Bill: Yes. It can't depend on the helium gas itself that…
David:…that the vocal cords….that there will be other vibrations in the vocal cords. That must be the same for both gases.
Bill: Instead the change is when the sound is transferred from the helium gas to the air.

The teacher understands that the group has been on the wrong track and suggests that the group make a comparison with an organ pipe that is filled with helium. Bill draws a picture of a pipe with a standing wave on the whiteboard. The group argues that the wavelength should be the same if air is replaced with helium in the pipe and they conclude that the frequency must then be three times higher.

The group seems to have solved the problem with the help of the analogy with the pipe but Ron is not satisfied with this solution. He still worries about what will happen when the sound leaves the helium and enters the air. Ron then examines the relation between speed, frequency and wavelength that they have written down. Since the speed of sound decreases when the sound leaves the helium in the mouth he thinks that the frequency should also go down. Bill agrees with him and says that the high frequency that was produced must return to normal when the sound comes out in the air. Ken, on the other hand, acknowledges that the frequency is higher already when it is produced in the throat and he questions that the frequency will change at the interface between helium and air. He makes a physical picture of the situation by beating his pen against the table top to illustrate what will happen at the interface between helium and air.

Ken:The frequency is higher, though. It will hit more often against the air when it arrives there. (He is beating his pen rapidly against the tabletop) Can the frequency be different?
Ron:No.
Ken:It must be like that…If you hit something…
Ron:It is this that will be changed.
Ken:Then the wavelength will be changed.
Ron:The frequency is formed here. It must be the same, though? Then it is the wavelength that changes.
Ken:Yeah, it is the wavelength that changes when it comes out.

Ron seems to accept that the frequency is constant. However, the group decides to be very explicit and writes down what is known before and after the sound passes the interface. They put numbers into their equations and find that the wavelength in air will be shorter than in helium. However, Bill is puzzled why the frequency does not change. Then Ken makes an analogy with light. He knows that when light enters into glass the light will have a different wavelength inside the glass.

Ron once again accepts Ken's explanation but Bill is now becoming more confused. He does not understand what decides whether wavelength or frequency will remain constant when the sound wave travels between media with different speeds of sound. Ron agrees with Bill and he quickly forgets the arguments from Ken. The discussion has now focused for a long time on what happens to the frequency and the wavelength at an interface. At least some members of the group seem to have forgotten that they had found that the frequency is higher already when it is produced in the throat. They have now returned to their original question on how the frequency can increase at the interface.

The group returns several times to the question if we hear differences in wavelength or in frequency. They quickly agree that it is frequency that we perceive with our ears. However, the question is still raised several times during the discussion. This might be a way for them to find another opening since they cannot get an increased frequency.

Ken:If we say that we have a boarder here. Here the waves are rather far apart. Then we come to this boarder.
Ron:Then it will be a different medium.
Ken:Then we will get a shorter wavelength. Then it will become a different frequency also?
Ron:Yes.
Bill: No, not if the velocity is increased here. It still will have time to do the same number of

vibrations. It travels much quicker. What do we perceive? Is it wavelength or frequency?
David: Frequency, I think.

The first group does not find a way to explain the phenomena. They become stuck in the discussion on what happens at the interface between helium and air. They have to ask the teacher if it is the wavelength or frequency that changes at the interface. The teacher gives some arguments to why the frequency cannot change which is accepted by the students and they continue directly to write down the solution that they were required to hand in.

In this group, Ron and Bill talk twice as much as Ken and David. Ron and Bill lead the discussion and write down the solution in the end. Ken does not say so much but he brings new (and correct) ideas into the discussion. Ron and Bill listen to Ken's ideas but they do not really include them in their own reasoning. The contributions from David consist of obvious conclusions and questions that do not belong to the main discussion.

The second group also focuses on what will happen to the frequency when the sound leaves helium and enters air. They realise that they need the speed of sound in helium and they use quite a long time to discuss how to get the sound velocity until they finally find a value for it in the text book. Like the first group, they assume that the vocal cords produce a certain frequency and they try to find a way to get an increased frequency at the interface between helium and air by manipulating the equation $v = f \cdot \lambda$. The teacher gives them the same hint as he gave to the first group and asks them to make a comparison with an organ pipe filled with helium. After a short while John has a clear picture and can explain for the others that the high pitch is produced in the throat in the same way that helium would produce a higher pitch in an organ pipe. The group is completely satisfied with this explanation and does not return to the discussion about what will happen at the interface between helium and air.

In the second group Charlie talks a lot, commenting on all ideas that are brought forward. John talks less but he introduces most ideas in the discussions. Many of them are incorrect which John realizes himself after a while. Ben talks less than John but he poses short relevant questions for the discussion.

The teacher had anticipated that the students should discuss the conditions for producing sound when helium fills the vocal organs. Instead the students in both groups discussed other things. First, they tried to calculate the speed of sound in helium by referring to theories for sound velocity in gases. This was not the intention of the teacher since it is easy to find a tabulated value of the sound velocity and using theories for sound velocities would require other data that are much harder to find. It would be a too difficult calculation so the teacher quickly made sure that the students did not spend time on this calculation. Second, the students incorrectly assumed that the vocal cords produce a certain frequency and therefore they focused on the transition of the sound from helium to air. They spent a lot of time discussing whether frequency or wavelength is preserved in such a transition. This was another unexpected discussion but it dealt with important concepts. That the frequency must be constant for a wave travelling between different media was neither brought up during lectures nor discussed in the textbook for sound waves. It is very briefly mentioned in the case of light travelling into another material but this had not been covered in the course yet.

In both groups, there were questions that popped up over and over again during the discussions. One example is the question whether we perceive frequency or wavelength with our ears. This question was raised several times in the first group and each time the group quickly agreed that it is the frequency that we perceive, but as they did not find a solution to the problem they returned to this question several times. This is an example of how the discussion went back and forth between different parts of the problem. The solution did not evolve in a stable linear pace.

Wittman et al. (2003) found that many students tend to think of sound in terms of objects. This might be a reason why our students were not sure that the frequency of the wave should be unchanged when the wave passes from one medium to the other. By treating the sound wave as an object, frequency is a property that could change like the speed of an object. If instead the wave is seen as a series of events it ought to be clear that the frequency cannot change by passing an interface. It seems that our students alternated between treating the sound as an object and as a series of events.

We can notice that the students had a strategy when they manipulated their equations, namely that in a relation between three physical quantities one should be held constant while the other two will depend on each other. They had no physical arguments to their assumption that either wavelength or frequency should be constant but the students start from this fundamental strategy. This strategy is often useful when solving physical problems but it is not always valid.

Students normally accept without any questioning that the frequency is constant when a wave enters a medium with different wave speed. This is the case for light entering a material with different index of refraction and water waves that enter a region with shallower water. That these students started to discuss that the frequency of the sound should change at the interface between air and helium should not be seen as a misconception, this discussion was provoked by the question that they could not find the answer to. This is similar to the discussion by Hammer (1996) of students' explanations to why it is hotter in the summer. Depending on the situation the students could come up with different answers to the question.

All students in these groups took part in the discussions and they were focused on the problem solving, they did not talk about other things. It was, though, a difference in how much each group member participated in the discussion. It is an interesting observation that although Ken, in the first group, gave correct explanations to what will happen at the interface between helium and air his ideas were never really accepted. One reason could be that he did not have the required status in the group so that the others would trust what he said. Another reason, which is supported by observations from the video recordings, could be that Ron and Bill were so occupied with their own problems that they did not take in what Ken said although they let him speak.

This group discussion shows that it is important that the teacher is present and can guide the groups to a correct explanation in the end. Several times, the first group made a correct description that the frequency does not change at the interface between two different media. When the teacher came to the group they still had to ask the teacher if it is the frequency or the wavelength that will be constant when the sound travels across an interface. Probably none of the groups would have come to the correct explanation by themselves.

This qualitative problem gave rise to lively discussions, even though our experience was that qualitative questions in general give rise to rather shallow discussions. We had previously observed that students did not work so hard with the question "Explain the reasons for the rainbow!". They could just note that different colours are refracted in different ways in a raindrop and be satisfied with this short explanation for the rainbow although there are many more aspects of the rainbow that are hard to understand. In the case with the helium problem, the students did not find a solution that worked. In this way they became eager to really try to understand what was going on.

Group discussion around a problem dealing with rotation of rigid bodies

The purpose of this group discussion is to give the students a possibility to discuss energy of rotating, rigid bodies and moment of inertia. These are new concepts for the students. Before this group discussion the students had attended three lectures on rigid bodies dealing with rotation of a rigid body, moment of inertia, torque and angular momentum. We video recorded two groups when they discussed and tried to solve the problem given below. In one group there were three male students (John, Mike and Alan) and in the other group three male students and one female student (Marvin, Ted, Ann and Alfred).

Who wins?

In an amusement park there is a racer track where competing persons go down the track in small carts with big wheels. The incline of the track is 30° to the horizontal plane. The carts have four wheels and every wheel has a mass of 20 kg and a diameter of 1 m. The total mass of a cart is 100 kg and the total length of the track is 60 m.

You visit the amusement park together with a boy. His mass is 30 kg. You two compete on this track several times and you always win. Do you have nature on your side and the boy nature against him? What final velocity do you reach?

In the first group John and Mike sit beside each other at a table. Alan comes a little later and sits down right opposite to John and Mike. Mike says in a while that the problem will involve potential energy and kinetic energy. He fetches the calculator and starts to calculate the potential energy for the different masses. John comments that this means that the one with the biggest mass will reach the bottom first. Alan says, "Does it?", but they don't discuss it any more. In a while John starts to talk about the moment of inertia.

John: But shouldn't we use the moment of inertia?

Mike: Yes, we can do that.

Mike looks into the textbook. John erases the whiteboard and Alan looks in his notebook. Mike finds something.

Mike: Perhaps. Force times the distance is equal to the work.

Alan: Mm.

Mike: So it is in this way you will get to know the force. The moment of inertia for each wheel times the distance. Look!

Alan: Moment of inertia, is that force?

Mike: It is force.

Alan: Can't we do as we did in the lecture.

Mike seems sure that moment of inertia is force, but the other students ignore him. Then the teacher comes by and Mike explains that they now talk about moment of inertia, but that his first thought was that the cart has potential energy and loses it which becomes kinetic energy. The teacher explains that this is part of the truth, but the moment of inertia should also be part of the solution. Mike asks again if moment of inertia is not force and the teacher explains that moment of inertia is for rotational motion what mass is for translational motion. The rotational energy must in some way be part of the solution, the teacher says. Now John seems to understand the problem and writes down that the potential energy is equal to translational energy plus rotational energy and so they find an expression for the final velocity. John and Alan discuss if the velocity will be bigger if the mass is bigger and they find that it will be so. John observes that they have solved the first part of the problem and says; "But then it is done."

John then points out that they also should calculate a value for the final velocity but they miss a value for the moment of inertia. He has earlier heard the teacher telling another group that one cannot know what the moment of inertia is, as they do not know what the wheels look like. Alan wants to suppose that the wheels are cylindrical shells. John is doubtful if they may assume such a thing. The teacher comes and John asks him if you can calculate the velocity if you don't know what the wheels look like and the teacher answers that they can make some assumption. They then calculate the velocity with the assumption that the wheels are hollow cylinders.

In this group the contributions to the discussion are rather equally distributed among the participants but a problem for the group is that they do not seem to rely on each other enough to be able to question the other students' arguments and to suggest improvements to them. Instead they want to hear what the teacher has to say. This group is also uncertain about the definition of many concepts and they have difficulties seeing what their formulas imply. Mike certainly lacks knowledge about moment of inertia and the other students in the group are not sufficiently competent and influential to protest loudly. The problem solving and calculation take a long time for them.

In the other group Ted starts the discussion by telling that he is not so familiar with this stuff.

Ted: Is there somebody who has a good idea? I have not had enough time to solve so many problems, so I'm not so familiar with this.

In this group there is another student, Marvin, who has ideas about how the problem should be solved. He suggests that they can use energy conservation and that they have to take care of the rotation of the wheels. They go on and discuss what the wheels do look like and if the wheels can be seen as solid cylinders or if there are spokes in the middle. They give examples of different types of tyres and Marvin suggests that they can take ordinary Opel rims, because then the centre is quite heavy. After some more discussion they agree that the wheels can be seen as solid cylinders. They write down the relation between potential energy, translational energy and rotational energy. They take the moment of inertia for the wheels to be a constant and so they receive an expression for the velocity and they argue that a larger mass will give a larger velocity. They go on and calculate the final velocity. The problem is solved.

They then start to write down the solution. They are taught to write down the solution according to the steps of the problem-solving strategy with motivations for all their steps, dimension analysis and a discussion if the result is reasonable. Alfred asks Ann to write up their results. Ann, who hitherto has mostly tried to follow the discussion, is in this way drawn into the problem solving. She starts to draw a picture and to write down the solution. Alfred gives her instructions on how to write down the solution. The students also discuss friction in the wheels and if it is friction just in the hub or somewhere else too. And so a discussion about how to write down the solution and a discussion about friction is going on in parallel for a while. They discuss rolling friction, sliding friction and air resistance but they don't seem to have a clear picture of what rolling friction is. Their conclusion is that friction can be of importance but they don't know how to handle it. In their written solution they write without any justification, that even if there is friction the greater mass is most important.

In the first part of the discussion it is mostly Alfred and Ted who have contributed to the discussion. Marvin has only asked one question and he has said "Yes," "Yes, it is so," "Suitable" which shows that he is following the discussion. Ann has first been away discussing with another group and then she has tried to follow the discussion but she has not contributed to it. Most of Ann's contributions come when she writes down their solution and then receives help from Alfred.

Neither of these two groups did function very well. In the second group two of the students were more active in the discussion than the other two. Ann was very unsure of her knowledge about the actual physics. "I know my shortcomings," she said. Though this group was not functioning well in every way, Alfred asked Ann to be the secretary and so he drew her into the problem solving discussion. In the first group Alan and John sometimes had productive discussions but overall it was difficult for this group to advance their solution on their own. They had to and wanted to receive help from the teacher. Mike was ignorant of certain physics concepts, but he did not question his own knowledge in the way Ann did.

Some of the students in these two groups seemed to be rather uncertain about important concepts and it was difficult especially for the first group to solve the problem. For the group discussions to function well the students have to be rather well prepared on the subject. This type of group discussions is intended to give the students an opportunity to discuss, interpret and apply physics concepts and principles and so deepen their understanding. It is not intended to be an opportunity to learn totally new concepts as for example in problem based learning.

The second group discussed thoroughly how to present the solution and they then followed the taught problem-solving strategy. This discussion was also a repetition of the problem solving and an opportunity for Ann to get involved and perhaps understand the solution. They also had a discussion on different forms of friction, although this discussion should preferably be followed by a discussion in class.

This problem about carts going down a track was not as engaging for the students as the problem in relativity. It is also rather unrealistic with the carts with very big wheels and where the child is allowed to go in his own cart. The students had occasional comments about the big wheels and one student said that he wouldn't like go by such a cart with the velocity 80 km/h. The problem is ended with a question: What final velocity do you reach? This question was added to give the students a hint that they could use the energy principle, but this question made the problem more like an ordinary task than a good context-rich problem. The question could be left out.

RESULTS AND CONCLUSIONS

The discussions in the groups went back and forth and the discussion did not evolve in a stable linear pace. The students had to discuss examples and other possibilities to be convinced of what is true, they compared with other problems they had solved and they used examples from everyday life. It was also important for the students to formulate conclusions and results from the discussions in their own words to really understand what it meant. When the teacher explained something for the students they often repeated the conclusions with their own words and then they went on with their discussion. These group discussions show that the students need to discuss physical phenomena, as for example length contraction, at length to really grasp all aspects of it. It is also clear that there are a lot of questions, which the teacher has not thought of as problematic, that can come up in the discussions.

The students were introduced to and supposed to follow a problem-solving strategy. Some groups followed the problem-solving strategy when they began their discussion making their own picture of the problem situation but others did not. A better use of the problem-solving strategy could probably have helped the students to organize their attempts to solve the problem. However, the groups might get into trouble even if they start according to the problem-solving strategy. In the case of the helium problem, both groups made the wrong assumption about the frequencies produced and the groups started to discuss a problem, which was there only because of their erroneous assumption. In any case the students used the problem-solving strategy when they wrote down the solution they were going to hand in and this gave them the opportunity to talk through the solution once again and to discuss the results. We agree with Leonard et al. (1996) that teaching problem-solving strategies focuses students' attention on the role of conceptual knowledge when solving problems. This is important even if such a strategy is not a golden rule for problem solving because students for example can lack relevant knowledge or start with a wrong assumption.

The students discussed physics concepts and principles nearly all the time in the group discussions. Misunderstandings of physics concepts reported in the literature emerged in the discussions now and then. However, when the students suggested that length contraction can be seen as an optical illusion, this seem to be just a suggestion on the way to a more profound understanding, not a real misunderstanding. When the students tried to solve the problem in relativity we find as did Scherr et al. (2001) that the relative simultaneity is a difficult concept for the students and they need a lot of discussion to realize that the simultaneity is relative. The students can also 'detect problems' that the teacher and the textbook do not see as difficulties. An example is what happens when the sound leaves helium and enters air. For the teacher it was rather obvious that it is frequency that is unchanged but this was not evident for the students. They needed a long discussion on this issue.

For the group discussions to function well the students have to be rather well prepared on the subject. If the students are too ignorant of the physics content they may just look in the textbook for formulas as they did in one of the groups that solved the problem in mechanics. This way of working does not lead to productive discussions and this group also had to get a lot of help from the teacher. Maloney (1994) points out that there exist studies that imply that working with problem examples is an important part of learning declarative knowledge but other studies imply that students need to have a solid knowledge base to be able to solve problems effectively. Our conclusion from this study is that the students need some knowledge of relevant physics concepts and principles when they start to solve problems in the group discussion but also that the group discussions are effective opportunities for learning and understanding physics concepts and principles.

If the groups do not function well this can lead to less productive discussions which was seen especially in the groups solving the mechanics problem. In one group two of the students were more active than the other two and in the other group they did not seem to rely enough on each other to be able to work on their understanding together. A more emphasized use of group roles and more evaluations and discussions of the group work during the course, as suggested by Heller and Hollabaugh (1992), might have made the group-work more effective for all students.

It is also important that the teacher is present and can guide the groups. This was shown in the first helium group where the group several times had made a correct description but when the teacher came to the group they still had to ask if it is the frequency or the wave-length that will be constant when the sound travels across an interface. To listen to the questions of the students can be an important occasion for the teacher to learn about students' difficulties with physics. It is important for the teacher to listen to the discussions to be able to treat important questions raised in the group discussions in a following lecture.

Maloney (1994) says that if we expect students to learn concepts and principles we may need to alter the form of the assigned problems. He mentions context-rich problems introduced by Heller and Hollabaugh (1992) as one possibility. Context-rich problems, however, can differ in content and form. The problem in special relativity was very engaging and the problem in mechanics less so. It is essential to put energy in designing good problems. The qualitative helium problem gave rise to lively discussions, even though our experience was that qualitative questions in general give rise to rather shallow discussions. The conclusion is that qualitative questions as other context-rich problems should be formulated so that they result in some puzzling experience for the students.

We find that group discussions around physics problems can lead to stimulating and learning discussions of physics. The students discussed physics concepts and principles and evolved their knowledge gradually. Misunderstandings known from the literature came up in the discussions but the students also detected new 'problems'. In the discussions most misunderstandings and problems were treated and solved either by the students themselves or by the students together with the teacher. Factors that stimulate a good discussion are engaging problems and a teacher at hand to answer questions and to discuss with the students. A taught problem-solving strategy can also in some occasions be valuable. Factors that can prevent a fruitful discussion are too little knowledge of the actual physics among the students and bad functioning of the groups.

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