

Conversation and Context in Physics Education

Abstract

The main aim of this project is to maintain and increase the students' interest in physics, especially the interest among the female students. This main aim will be achieved by increasing the opportunities for conversations and discussions of physics. We also want to place the physics content in a context that is interesting for the students. That could be done by connecting to phenomena in everyday life or to some possible future career, by discussing technical applications, or by describing the historical context of physics and its impact on society. We also want to make the teachers aware of and discuss the influence of gender on physics teaching and learning.

During the first year of the project we have had seminars in which we have discussed the importance of student activity, context in physics education and also gender issues. Two of us made a visit to USA to learn about the ways of teaching physics that have been developed at the University of Minnesota and the University of Washington. Their work has inspired our project from the beginning. Especially the way they use context-rich problems in Minnesota has influenced our thinking.

We have constructed context-rich problems for different areas of physics and we have also planned qualitative questions and some simple experiments suitable for student discussions around physical concepts.

The new ways of teaching will be implemented during this academic year, 1999/2000. We plan to replace approx. 50% of the lectures with seminars in which the students are active and to stress context in the courses. We practise these methods in five courses during the first year of physics studies at the university. We also start to evaluate the context-rich problems and the teaching and learning activities during this year.

During the third year of the project we adjust our teaching methods according to the student evaluations and the whole project is finally evaluated.

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Final report

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Introduction

In this report we describe the development and results of the project "Context and Conversation in Physics Education". At the beginning of the project the following aims were stated.

The main aim of the project is

- ★ to maintain and increase students' interest in physics, especially among the female students.

This main aim is achieved by

- ★ increasing the number of opportunities for conversation and discussion of physics, both among student and between teachers and students,
- ★ placing physics in a proper context. That can be done by connecting to phenomena in everyday life or to some possible future career, by discussing technical applications, or by describing the historical context of physics and its impact on society,
- ★ making the teachers aware of how a gender perspective on physics and physics education can influence teaching.

The wish to change our physics teaching has a background in the discrepancy between our teaching philosophy and the actual teaching in most physics courses at our department. Our intention to especially consider female students is to a great extent a result of experience and work in the field of gender and science by one of us (Benckert 1998).

We intended to accomplish these aims by changing the first year of physics studies at the university. We wanted to put physics in a proper context and to introduce more student activity based parts in which understanding of basic concepts were emphasised. Our goal was to replace approximately 50% of the lectures with seminars where the students were active. Our intent was to introduce these changes without altering the course syllabus, and teachers, who are not burning for new pedagogical ideas, should nevertheless be able to teach according to the new model.

In this report we first give a short background of our ideas and work. We present some arguments on why physics is associated with masculinity and report about research on learning in physics. We then describe investigations of student attitudes towards physics learning and compare with our own results from a questionnaire. We describe the work done in Minneapolis on context-rich problems and give examples of what a context-rich problem can look like. We describe how we have transformed the ideas from Minneapolis to our

Swedish university settings and what our new teaching and learning model does look like. We end with a discussion of the impacts of the project and draw some important conclusions.

Gender and physics

Few women begin to study physics in Sweden and of those few some drop out without completing their studies. One reason why there are so few women in physics is that physics in many ways is associated with masculinity. As Kim Thomas (1990, p 181) points out: "Higher education does not reproduce gender inequality by actively discriminating against women. What it does is to make use of culturally available ideas of masculinity and femininity in such a way that women are marginalized and, to some extent, alienated." The female physics students in Thomas' study had to try hard to be 'as good as the men' and to be like men. For the male students, studying physics affirmed their masculinity and also their importance in a reassuring circle. On the other side the female students in physics were much less self-confident than the male.

Science and especially physics is seen as an objective, rational and value free enterprise. This image of physics does not only hinder women from studying physics, it may also have consequences for physics itself, as pointed out by Evelyn Fox Keller (1992 p 20). The high value of objectivity and perhaps a fear of subjectivity can be the reason for the impersonal and detached language and writing in science. One writes, "It has been observed..." Who has observed? Observations are always made by human beings living in a society and a culture and this impersonal language makes this invisible and so the relevance of history, time, place, culture, author and personal responsibility is also denied. Traweek (1988) describes the culture of high-energy physics as an extreme culture of objectivity: a culture of no culture.

The high value of objectivity and impersonality may also have an effect on the teaching in physics (Benckert 1997). The content of physics courses and physics problems are often idealized and removed from real life context.

The association of physics with masculinity and the connection with the ideal of a hard, abstract, value free and pure physics tends to exclude women more than men. It is therefore important to try to change the learning milieus in physics so that the female students can feel comfortable and become confident of their knowledge in physics. Women often appreciate a collaborative working atmosphere and dislike highly competitive lectures and evaluations. Sheila Tobias (1990) found for example that most women found physics classrooms an "unfriendly" place to be in. She also found that students, who did not pursue science at the college level for a variety of reasons, wanted changes in classroom culture, more of context in the presentation of physical models and more of discussions.

About learning in physics

In the last two decades several studies on learning and teaching in physics have been realized. These investigations deal with different school levels, from lower secondary school to university level. In Sweden the interest has hitherto been on lower secondary school level. In USA there has been a greater interest in university students' learning. It has been clearly shown that students in general have trouble understanding and using physical concepts. Students often have misconceptions regarding profound physical concepts even after they have passed physics courses at the university level. Lilian McDermott and the Physics Education Group at the University of Washington have for a long time investigated students' difficulties with concepts in different areas of physics. In recent years such research has spread also to other universities in USA. An overview is given by McDermott & Redish (1999).

Hestenes et al (1992) have designed a test to probe students' grasp of central concepts in Newtonian mechanics. This test has been widely used and Hake (1998) has made a survey of pre- and post-test data for high schools, colleges and universities in USA using this test. He shows that the improvement of the results between pre- and post-test is larger for students in courses using interactive engagement methods compared to courses with traditional teaching methods.

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 et al. (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.

At the University of Minnesota (Heller & Hollabaugh 1992) they combine teaching a problem solving strategy with a supportive environment to help students implement this strategy. The students practice problem solving in small groups. The problems used are so called context-rich problems. That is real-world problems where there is a motivation or reason for the students to want to know about the actual events and not just to find an answer to compare with the answer in the textbook.

The work done at the University of Minnesota with cooperative groups solving context-rich problems seemed to us to be a way to introduce both more of context and also group discussions among our students. This can also be a way of learning physics that is more attractive to women than traditional teaching methods. We describe the work done at the University of Minnesota about context-rich problems in more detail later on in this report.

Whitelegg and Parry (1999) also discuss real-life contexts for learning physics. They conclude that the context can come in as an application of a scientific principle after teaching theory or physics can be taught with the starting point in appropriate contexts. They are of the opinion that to increase students' interests teaching and learning should start with problems from an appropriate context, which is familiar for the students. In their project (SLIPP) the chosen context then defines what physics content that should be treated. This project has produced eight units of material in physics for post-16 students. Examples of titles on these units are *Physics for Sport* and *Physics on a Plate*.

Rennie & Parker (1996) have investigated the effect of context in physics problems by comparing the performance of physics students on two sets of matched problems, one set included problems embedded in a real-life context and the other set included abstract problems without reference to real-life events or objects. They found that the students performed better on the context-rich problems and that they found these problems more interesting.

Attitudes towards physics

An important part for the success of learning is the student's attitudes and beliefs about university physics. Redish et al. (1998) have made a survey of students expectations, before and after introductory physics, at six universities and colleges in USA. They found that many students do not have the attitudes towards physics and learning as an "expert" would like to see. Even worse, the result deteriorated after instruction. The most serious part was that fewer students saw a connection between physics and real life. Many students also thought that physics was to a large extent a matter of finding the right equation and plug in numbers.

We handed out a questionnaire to the students, which consisted of statements on physics as a subject and on the teaching situation. The students were asked to mark on a five-point scale to what degree they agreed with the statements. The students were given the same questionnaire in the beginning of their physics studies and in the end of their first year with physics. We made this study twice, first with a group of students that were taught the traditional way and then with the first students that worked with group discussions on context-rich problems. In this way it would be possible to see if the student's attitudes changed during their first year of physics studies and also if these changes were depending on the way of teaching.

The clearest change during the year of physics studies was found for the students with traditional teaching and their attitudes to using the textbook. There were fewer students that considered it important to read the textbook carefully when they answered after one year of physics studies than when they answered in the beginning.

There was also a tendency that the students changed their attitudes so that they wanted more detailed instructions for the lab work and they were less keen to solve problems without a distinct answer. These tendencies were not seen with the group that worked with group discussions. The clearest change in their attitudes was that fewer students thought that solving physics problems meant to find the right equation. It must be stressed, though; that the groups are small and even in these "clearest" cases the observed changes are not statistically significant.

Context-rich problems and problem solving in cooperative groups

We visited the Physics Education Group at the University of Minnesota the first year of the project and learned about their way of teaching physics. The main points of their work are summarized in two articles in *American Journal of Physics* (Heller, Keith, Andersson 1992 and Heller & Hollabaugh 1992).

The University of Minnesota has developed and tested an approach to help students in physics courses to integrate the conceptual and mathematical aspects of problem solving. They have done this by explicitly teaching a problem-solving strategy and by having students practice solving problems in cooperative groups. Heller and Hollabaugh (1992) point out that the success of the approach is dependent on two factors. The first factor is the type of problem the students are given to solve and the second factor is the formation and maintaining of well-functioning cooperative groups. While solving ordinary, idealized end-of-chapter textbook problems group discussions tended to revolve around "what formulas should we use". On the other hand, in real-world problems there is a motivation or reason for wanting to know about the actual events. Before mathematical manipulation of formulas begin, the students have to decide which variable would be useful to answer the question, what physics concepts and principles could be applied to determine that variable, what information would be needed and where and how that information could be obtained or estimated. At the University of Minnesota they showed that context-rich group problems focused students' discussions on "what physics concepts should be applied" rather than "what formulas should we use".

The context-rich problems used in Minnesota had the following characteristics.

1. Each problem is a short story in which the major character is the student. That is, each problem statement uses the personal pronoun "you".
2. The problem statement includes a plausible motivation or reason for "you" to calculate something.
3. The objects in the problems are real - the idealization process occurs explicitly.
4. The problem cannot be solved in one step by plugging numbers into a formula.
5. More information may be given in the problem statement than is

required to solve the problem, or relevant information may be missing.

6. The unknown variable is not explicitly specified in the problem statement.
7. Assumptions need to be made to solve the problem.

A context-rich problem does not need to include all seven points but the two first should always be included.

A typical, traditional problem in a mechanics course can be as follows:

A traditional problem A 5.0-kg block slides 0.5 m up an inclined plane to a stop. The plane is inclined at an angle of 20° to the horizontal, and the coefficient of kinetic friction between the block and the plane is 0.60. What is the initial velocity of the block?

There is not much of motivation for a student to solve this problem except that the teacher expects the student to solve it. This problem as a context-rich problem can look like the following.

As a context-rich problem

You visit Sollefteå, a very hilly, Swedish town. When you are driving up a steep hill, a small boy runs out in the street in front of you. You slam on the breaks and skid to a stop. The boy, who had chased a ball, runs away with the ball under his arm. A policeman watching the accident comes up to you and points out that the speed limit is 50 km/h and he gives you a ticket for speeding. When you have calmed down from this shaking event you start wondering if you really drove too fast. You can distinguish the skid marks on the street and you measure them to be 18.2 m. You also estimate that the street makes an angle of 20° with the horizontal. In the owners manual of the car you find that the mass of your car is 1570 kg. Your own mass is 58 kg. A witness tells you that the boy had a mass of 30 kg and that he crossed the 5 m wide street in 3.0 seconds. You contact a tyre manufacturer and he informs you that the coefficient of kinetic friction between your tyres and the street surface is 0.6. The coefficient of static friction is 0.8. You also measure the contact area between a tyre and the street. It is 1.2 dm^2 . Will you fight the ticket in court?

The problem is more difficult as a context-rich problem but also more motivating for the students to solve. It is meaningful to solve this problem in a cooperative group because the problem is more difficult and not so easy to see through. The problem now includes additional information that can lead to discussions about what really is necessary to know to find a solution to the problem.

Another example of a context-rich problem constructed by us for a course on waves and optics is shown below.

A context-rich problem for a course on waves and optics

It is a great honour for you to have been invited by the Royal Swedish Academy of Sciences to give a talk on your research results. You would, of course, like to give a good impression so you use a lot of time for your preparation. Before you start to write your overhead sheets you look for information on the lecture room so that you will be sure to write large enough characters that everyone can read. You make a call to Stockholm and get hold of a caretaker who tells you that the room is 20 m long and 10 m wide. The OH-pictures are projected directly onto the upper part of the front wall, which is 8 m high. The first row for the audience makes it impossible to place the OH-projector more than 4 m from the front wall. You realize that you need to know more about the OH-projector and with some persuasion the caretaker digs out some information. The OH-projector is of a standard model with an adjustable mirror, which reflects the light onto the wall. According to the manual the projector has a Fresnel lens with a focal length of 12 cm and a biconvex lens with a focal length of 35 cm.

Which size should you have on the characters that you write on your sheets?

When all extra information has been taken away the solution to the problem is identical to the solution of the following traditional problem, except for the numbers used.

As a traditional problem

An image of a candle is formed on a screen with a lens with a focal length of 35 cm. The distance between the lens and the screen is 2.0 m and the image of the candle is 70 cm high. What is the height of the candle?

Heller and Hollabaugh (1992) found that the optimal group size for problem solving was three students. A three-member group is large enough for generation of ideas but small enough so that all students can contribute to the problem solution. They also found that instructor-assigned groups of mixed ability (e.g. a high, a medium and a low ability student) performed as well as groups consisting of only high-ability students, and better than groups with students of only low or medium ability. They also assigned different roles for the group members to facilitate the group work. The roles were Manager, Sceptic and Checker/Recorder. The Manager keeps the group on task. The Sceptic helps the group to avoid quick agreement and pushes members to explore all possibilities. Checker/recorder checks for consensus in the group and writes down the group solution.

We were impressed and inspired by our visit at the University of Minnesota and we used their ideas about group discussions and context-rich problems and transformed them to our Swedish conditions.

Context-rich problems and group discussions in the Umeå-project

We have in Umeå introduced group discussions around context-rich problem

in five physics courses. It is courses in mechanics, electromagnetism, thermodynamics, waves and optics and quantum physics. The students take these courses during their second year at the university and these students study in the Physics Programme or they are in a teacher-training programme and intend to be teachers in physics at upper secondary school. We decreased the time for lectures and introduced instead group discussions.

In our group discussions the students mostly solve context-rich problems but we also have some group discussions where they discuss qualitative questions. If group discussions are devoted to discussion of qualitative questions it is very important to follow up the discussion in a proper way and the instructions to students must be very clear. The context-rich problems do engage the students much more. We, the teachers, often underestimate the time needed for the students to discuss and solve these problems. In Minnesota the students worked with context-rich problems for 50 minutes at a time. Our students get 2 to 3 hours to solve one or two context-rich problems. They use the time to discuss and solve the problems but the problem solving also leads to profound discussions of physical concepts, so the time is well used.

We have also introduced a problem solving strategy, similar to the one used in Minnesota. The first and very important step in the problem solving strategy is to visualize and describe the problem. Step two is to describe the physics that can be used. Step three is to plan the solution and step four to execute the plan. Step five is about evaluating the answer and this is also very important and often forgotten in traditional problem solving. The introduction of the explicit problem solving strategy has improved the solutions of examination problems. The students now for example include a dimension analysis and discuss if the answer is reasonable.

We have as in Minnesota found that groups of three students are ideal in our group discussions. The group roles, Manager, Sceptic and Checker/Recorder were 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. Especially the Sceptic is essential to get the problem solving to work well.

A great deal of the work in the project has been devoted to construction of context-rich problems suitable for our courses. You have to construct problems that are motivating for the students, not too easy to solve but not too difficult either and the problems should be well suited to the actual course. It has been great fun to construct the problems but of course we have also met problems. It is for example much more difficult to construct good context-rich problems in quantum physics compared to mechanics.

The most important point in the context-rich problem is that you ask for something that can be interesting to know. This seems to be a trivial observation, but if you study traditional physics problems with critical eyes, you will discover that this is not always the case.

The context-rich problem is written as a short story where the student ("you") is the major character. The story gives the context, so it is important, but how important is the address "you"? We have found, that if we try to write a problem where "you" is the major character, it is easier to find relevant contexts and questions and to write the problem in a way that is motivating for the students and easy to understand.

The conversation with the students during the group discussions give the teachers insight into the students' difficulties in understanding physical concepts and how to apply them. These experiences can be used to direct lectures and group discussions to areas where the difficulties are the greatest. This project has also lead to more contacts between the teachers of the different courses. We have planned the courses, the group structure and the evaluation of the courses together. All the teachers have seen this as very positive.

Student views

The students have continuously evaluated the courses involved in the project. After two weeks on a course the students have been asked to answer a small questionnaire ("backspegel"). It has consisted of 3-4 questions about how the course has worked out so far. A special concern was given to the working climate in the groups. After completion of the course a larger questionnaire has been handed out which has been followed up by a discussion between the teacher and 3-4 students.

Most of the students think that the group discussions work well. There are many positive comments. "Group discussions are great. You learn a lot, both when you explain to others and when someone explains to you." "Group discussions are incredibly good. It is good that you have to get engaged." There are 2-3 students that in the end of the year say that they have got tired of group discussions. All the female students, though, appreciated the group discussions and some of the women were very enthusiastic about it. The cooperation has worked well in most groups but there have been some comments on group members that don't contribute to the discussion or that have difficult to accept others view points.

Group discussions on context-rich problems have worked the best and engaged the students the most. Other types of questions for the discussions were taken as vague and unimportant. Such tasks demand that the groups are required to report their findings. This is not the case for context-rich problems where the students work hard even when they don't have to report their results.

Some students thought that there had been too many group discussions in some courses. They suggested that there should be more problem solving classes instead of some group discussions. There were also a suggestion of more lectures instead of group discussions but most students seemed to be happy with the amount of lectures given.

Impacts of the project

The project is now finished but group discussions around context-rich problems are still in use to the same extent as during the project and we see these teaching/learning methods as successful. When the project started some teachers in our department were rather sceptical to our ideas. They are less sceptical today. Some teachers, who have not been involved in the project, have expressed desire to try to use this method in their courses.

We have had a workshop around context-rich problems and group discussions for physics teachers from upper secondary school. They were enthusiastic about it and we know that some of the participants have used context-rich problems in their own courses. We have also presented our work at a pedagogical conference at Umeå University and at a science education conference in Falun 2001. At both these conferences this work raised interest and the question if these ideas could be used also in other science subjects were discussed.

The project has been presented at the international GASAT-conference in Copenhagen 2001. At this conference the gender issue in the project was in focus (Benckert 2001). The project was also presented at the Quality Conference of Higher Education in Norrköping (Benckert & Pettersson 2001).

Three physics teachers from Mälardalen University College visited our student group during a group discussion session to experience what such a discussion around context-rich problems really was about. They have then constructed and used context-rich problems in group-discussions in a course at Mälardalens University College. They report that most students appreciated these discussions but they did not attain as good problem-solving ability as the teachers had expected.

As a follow-up of this project we have applied for and got some money from the Swedish Research Council to plan a research project about the construction of context-rich problems, group discussions and gender aspects of these issues. This will be done together with teachers from Mälardalen University College and teachers from upper secondary school.

Conclusions

Group discussions about context-rich problems are very adequate to raise lively and fundamental discussions about physical concepts and principles. Problem-solving strategies can also be learnt through these group discussions, as the context-rich problem is enough complicated to need a problem-solving strategy.

The group-discussions lead to insight into the students' difficulties in understanding physical concepts and how to apply them. These experiences can be used to direct lectures and group discussions to areas where the difficulties are the greatest.

It is important that the context-rich problems are written as a short story that motivates the students. We found that the address "you" in the problem can be a way to achieve this aim.

Women are often silent in large groups such as in classrooms. In the small cooperative groups they get a better chance to speak and to participate in the discussions. Women tend to like the collaborative working atmosphere in the discussion groups. Women are more dependent than men on discussions to really convince themselves that they do understand the physics. It is also more important for women to see the connections between physics and real world phenomena. In these aspects we think that our project leads to a better milieu for women in physics.

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