Open-ended problems in physics
Upper secondary technical program students’ ways of approaching outdoor physics problems

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Abstract

This study reports on technical program students’ approaches to solving open-ended problems during an introductory physics course in a Swedish upper secondary school. The study used case study methodology to investigate students’ activities in outdoor context. The findings come from observations and audio recordings of students solving three different open-ended problems. The results showed that the students had difficulties to formulate ‘solvable’ problems and to perform necessary ‘at home’ preparations to be able to solve the problems. Furthermore, students preferred to use a single solution method even though different solution methods were possible. This behavior can be attributed to their previous experience of solving practical problems in physics education. The result also indicated need of different levels of guidance to help the students in their problem solving process. A tentative conclusion can be made that open-ended problems have an educational potential for developing students’ understanding of scientific inquiry and problem solving strategies in the process of performing practical outdoor activities.

Keywords: case study, out-of-classroom context, problem solving, student difficulty
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Introduction

My interest of physics has given me the opportunity to study physics from two different perspectives: as a student for Degree of Master of Science in Engineering Physics, and as a student for the Degree of Master of Education. During my studies at different levels in physics I have noticed that the types of problem and solutions methods are similar despite level difference. Usually, the problems are ‘closed’ because they ask for a specific numerical value or a particular explanation. Preparing recently for doing my Master thesis in Education I begun to review my own experiences of physics lessons at both upper secondary school level and university level in Sweden.

When I studied physics at upper secondary school level I remember that the majority of the lessons were performed in the same pattern; the teachers tried to transfer their knowledge and the information from textbooks to me by using words and writings on the whiteboard, and audiovisual technology as overhead projector was used to illustrate pictures. Furthermore, the questions the teachers asked during the lessons were ‘closed type questions’ because the teachers expected particular answers known in advance.

The problems we needed to solve could be found at the end of every chapter, and these problems could be solved by starting to identify the unknown and given variables. It could be said that the method of solution was to find a suitable formula to apply the given numerical values and find the unknown value. Moreover, a physics handbook was helpful if the formula was not known by heart. The formula could also be found in the corresponding chapter of the textbook. Sometimes a problem needed several formulas to be solved, and the difficulty was to use mathematical skills to perform algebraic operations on the formulas. This procedure ended up with an expression that included all given values, and then the unknown variable could be determined. The important thing with this procedure was to know which variable to determine and find a suitable formula that included the given values, and finally perform the calculation. It could be said that mostly it was not necessary to understand the physics concepts of the problem to be able to solve it numerically.

The laboratory works were performed in the classroom and they could be done by following detailed prescriptive instructions, and the results should be attained by using step-by-step method. It was common that the expected result was already included in the written instructions, and this made it easy to see if any of the steps were performed wrong. As a result, it was not always necessary to make own conclusions about the results.

I remember one lesson that was different in comparison with the usual physics lessons, and that was when the school was open on a holiday. The purpose of this school day was to show students’ family and relatives how the students worked during the lessons. During the physics lesson me and my classmates were told by the teacher to make a scale model of the solar system so it could fit in the classroom. Initially, we should use a given spherical object that would be the sun and the rest of the solar system would be constructed after the scale of the sun model. The scale model included both correct size of the planets and the correct distances between them. We made the numerical calculations and our conclusion was that the current scale of the solar system would be too big to fit inside the size of the classroom. Therefore, we needed to reformulate the problem and construct a new model of the solar system that could fit in the classroom, but now the planets became too small to be constructed from suitable materials. As a result, we needed to abandon the criterion that the solar system should fit inside the classroom, and the problem needed to be reformulated again. Hence, I remember this episode because it made me realize that there is not always one correct answer in a physics problem. It can be said that it depends how the problem is formulated. Another reason why I remember this episode was that we got the opportunity to develop and try out our ideas
and make our conclusions from the results we gained, because the result was not predetermined.

I have studied physics at different level at the university as master student in Engineering Physics. According to my experience, the teaching methods do not differ much in studying physics between upper secondary school level and university level in Sweden. The obvious difference was the level of difficulty, but the university lecturers taught in the same pattern as the teachers did at upper secondary school level. In my opinion, many physics courses at university encourage students to use the same problem solving strategies that have been used at the upper secondary school level. The strategies included the determination of the unknown and given values and then to find a suitable formula. Furthermore, one can argue that the physics exams at university level do not differ remarkable from year to year, because the same or similar problems can be given at two different exams. For example, if the student knows the algorithmic procedure to solve the problem, then it is not always necessary to understand the physics behind the problems to be able to pass the written exam. Physics exams often required a correct expression or a correct numerical value as an answer, and the arguments are often embedded into the formulas that are used to solve the problem.

I needed to complement my knowledge in physics with courses in pedagogy to get a teaching degree in physics, and during the theoretical parts of the courses I understood the importance to motivate and create interest for students in my subject. In contrast to my own experiences of the physics courses at upper secondary school level I found disagreements when I studied the policy documents. For example, Curriculum for the non-compulsory school system Lpf94 stresses that the students should be active during the lessons, and they should also be encouraged to take responsibility for their studies (Skolverket, 2006). However, during my School Based Studies (VFU) in teacher education I got the opportunity to come back to the issue of the ‘students influence on their studies’ from the teacher’s side, and my experience showed that the influence of the students is mostly exercised to determine how many tests the course should include. Otherwise I think my own experiences of ‘passivity in physics classes’ corresponds to the situation of the current students.

During my School Based Studies the thought of how to create more interest and activity in physics among students started to develop. I noticed that the physics problems were of the same type and solvable with the same procedure as when I studied physics at the upper secondary school level. For that reason I wanted to involve the students more in the lessons, for instance, let them make their own decisions when they solve problems, and also let them be more responsible for their studies. Furthermore, work with open-ended physics problems seemed promising way to go, because an open-ended problem can both have several correct answers and several different solution methods. In this case I performed a small study to find out how familiar students were to work with open-ended problems in outdoor context and if it was possible to include this type of activity in the traditional physics lessons. My results showed that the students were very unfamiliar to work with open-ended problems in their physics studies. The study also indicated that students’ work with open-ended problems in physics in new contexts needed further investigation because it was an appreciated feature among the students who performed the outdoor experiment (Sverin, 2011).

Therefore, I decided to do a study about how students work with open-ended problems in physics, and the benefits and difficulties it may bring when they perform their investigation in out-of-classroom context. That is what my current study will be about.
Background

Curriculum Framework

This study was made in the context of Swedish upper secondary school system, and therefore framed by the corresponding curricula. The policy documents used for this study were Physics A course plan and the curriculum for the non-compulsory school system. Currently, two versions of the policy documents are valid, because the Swedish upper secondary school is under reform and the validity of these documents depends on when the students start their education. For example, if the students started their education before fall 2011 their education follows the former curriculum, *Curriculum for the non-compulsory school system Lpf94*. In similar way, if the students started their education after fall 2011 their education follows the new curriculum, whose title can be translated into *Curriculum for the non-compulsory school system Gy11*.

*Curriculum for the non-compulsory school system*

The curriculum for the non-compulsory school system describes the school’s fundamental values, aims and guidelines. In the following examples the Swedish version of the documents uses the same formulation of the texts, where only the former version has been published in English. In the case where the formulation in Swedish does not conform to the English version a notification of translation is made.

_Pupils shall train themselves to think critically, to examine facts and their relationships and to see the consequences of different alternatives. In such ways students will come closer to scientific ways of thinking and working* (Skolverket, 2006, p. 5; 2011A, p. 3)

...[the pupils] can use their knowledge as a tool to:

- formulate and test assumptions as well as solve problems
- reflect over what they have experienced
- critically examine and value statements and relationships
- solve practical problems and work tasks (Skolverket, 2006, p. 10; 2011A, p. 6)

...The teacher shall:

- take as the starting point each individual pupil’s needs, preconditions, experience and thinking
- in the education create a balance between theoretical and practical knowledge that supports the learning of pupils (Skolverket, 2006, p. 13; 2011A, p. 6-7)

...The teacher shall:

- take as the starting point that the pupils are able and willing to take personal responsibility for their learning and work in school,
- plan and evaluate the education together with the pupils
- encourage pupils to try different ways and structures of working (Skolverket, 2006, p. 15; 2011, p. 8-9)

Furthermore, the former curriculum, *Curriculum for the non-compulsory school system Lpf94*, describes that
Pupils shall develop their ability to take initiatives and responsibility and to work and solve problems both independently and together with others. (Skolverket, 2006, p. 5)

In comparison with the former curriculum this part has been extended in the new curriculum with respect to the school’s responsibility towards the students:

The school shall stimulate the pupils’ creativity, curiosity and confidence and their willingness to try and convert new ideas into actions and problem solving. The pupils shall develop their ability to take initiatives and responsibility and to work and solve problems both independently and together with others (Skolverket, 2011 A, p. 4 author’s translation)

In this study the former curriculum document was used, because the case study group started their education before fall 2011. The changes in the new curriculum are interesting to take into consideration, because the curriculum describes that the students shall henceforth be encouraged to try new ideas. Students’ work with open-ended problems can give them opportunities to try different ideas, both their own ideas and ideas suggested by others.

Course plan

The course plans are compliments to the curriculum, and they specify the aims and goals for every school subject. For example, some of the goals in the Physics A course plan are:

- Pupils shall be able to participate in the planning and carrying out of simple experiment investigations, as well as orally and in writing report and interpret results.
- Pupils shall be able to reason over quantities in physics, concepts and models, as well as within the framework of these models carry out simple calculations.
- Pupils shall be able to describe and analyze some everyday phenomena and processes with the help of concepts and models from physics. (Skolverket, 2001, p. 40)

These goals can be described as non-related to physics topics, because they are not directly related to students’ knowledge about different topics in the course. Hence, the students should be able to achieve these goals regardless to which physics topic they are studying.

A comparison between the two course plans shows that aims that are included in the new course plan and not included in the former course plan are:

- The teaching shall take advantage of current research and pupil’s experiences, curiosity and creativity.
- Pupils shall develop ability to critically examine statements, and to distinguish statements on sound academic basis from non-scientific basis.
- The teaching shall provide pupils with knowledge about physics relevant to the individual and society
- The teaching shall include scientific methods, which are to formulate and search answer for questions, design and perform observations and experiments, and process, translate and critically examine results and information. (Skolverket, 2011B, author’s translation)

According to the last point, a difference between the two course plans is that the focus of the scientific methods has been intensified. For example, the students shall formulate questions, which they were not required to do in the former course plan. This emphasizes the importance of the study’s investigation of students’ work with open-ended problems because the new course plan will soon be the only valid version.
Issues raised by educational researchers and evaluators

Educational researchers and evaluators have raised issues about the situation of physics education in Swedish secondary schools. The issues are concerning students’ interest and perception about the physics subject, the current teaching methods in use and the lack of effect of laboratory work.

Poor academic achievement can be attributed to low interest from students as well as motivation and low understanding in physics (Skolinspektionen, 2010; Prytz, 2003). A number of factors may be underlying reasons for the development of low interest in lower secondary level of physics, and the contributing factors can be textbooks, classrooms and teachers. Therefore, students’ lack of motivation can be related to that they do not think the physics is interesting or relevant, because they might not see any relevance in the subject matter. This lack of sense of reality could possibly increase the disinterest and decrease the student’s motivation to learn and understand physics (Skolinspektionen, 2010).

Similar issues with physics education have been discovered in Germany, where secondary and college education experienced massive and decreasing loss of students’ motivation with regard to science. A possible explanation to the loss of students’ motivation could be the reforms of secondary and college education in the seventies and eighties, where the students were introduced to more options in their education selection. As a result, students’ interest in science as a whole declined and the most unpopular subjects in German schools are mathematics and science, where physics is disliked most (Riess, 2000).

Educational evaluators argued that the quality of the physics course in Sweden is poor and students’ perception of the lessons is dull and uninspiring. The current physics lessons can be described as a review of well established scientific knowledge, and transmission pedagogy is used during these lessons, i.e. the knowledge is transformed from a source to the relatively passive students. The result of the transmission pedagogy can be attributed to students’ perception of physics as formula-based, and therefore, students try to learn the formulas by heart without understanding the correct physics representation. Furthermore, the current physics lessons stress the tradition of teaching a conceptual and substantive knowledge material, but the lessons do not stress the scientific facts and arguments or identifying scientific issues. Consequently, it is possible that the students get the idea that it is not necessary to learn why using certain physics concepts, and frustration could be created among the students. The cause of low interest in physics can be attributed to other factors than the intellectual challenges in the physics lessons. For example, created frustration along with passive learning, memorization of formulas and the perception of irrelevant topics can contribute to the low interest. In addition, laboratory work can be attributed to the low interest due to the fact that it is rarely linked to everyday phenomena (Skolinspektionen, 2010).

Laboratory work in the physics course should give the students the opportunity to understand physics, but if the students do not realize the usefulness of laboratory work it will possibly not contribute to students’ understanding of physics concepts. Furthermore, discussions between teacher and students are rare in lower secondary level and students themselves often carry out experiments in small groups without supervision from teacher. It could be said that the laboratory work does not attract students’ interest. Written instructions without opportunity to formulate own questions are common, and the laboratory work in the classroom does not create conditions for deeper discussions. For example, one condition for deeper discussion in physics could be students’ knowledge of connection between theory and laboratory work, but this condition is not fulfilled (Skolinspektionen, 2010).

Physics can be perceived as a difficult school subject, and then it is necessary to have a balance between the difficulty and students’ motivation and ability. Furthermore, physics is
usually associated with the use of formulas for calculating values, but deeper understanding of physics requires more knowledge than managing algorithms for solving problems (Skolinspektionen, 2010).

Skolinspektionen (2010) suggests some solutions to the problems in the current physics education to create opportunities for successful learning.

- It is necessary that the teacher identify the individual level for every student and challenge it in an appropriate way.
- It is necessary that the teacher has the ability to explain physics in different ways to be able to meet different kinds of students.
- Teachers who convey the desire to learn have often lessons related to reality, and they engage students in challenging discussions and show how theoretical knowledge can be used in practice.

Furthermore, successful learning depends on two-way communication and discussion between teacher and students, and therefore, if the students are aware of their ability to learn they can also plan the lessons together with the teacher. However, increased desire to learn does not automatically lead to that students reach better academic achievement, but the development and progress in the highlighted areas will give potential to increase students’ desire to learn. Increased desire to learn can create opportunities to achieve better learning outcomes in physics (Skolinspektionen, 2010).

Physics is the science of the nature, and therefore, observations can be seen as the first qualitative study of nature, and it is recommended to be performed out in the nature (Prytz, 2003). Slingsby agreed with this argument, because the author stated that the future of school science lies outdoors (Slingsby, 2006:51). Moreover, Slingsby (2006) stressed that the science course should introduce the students to think like scientists, and that implies to use scientific knowledge so the students understand the phenomena they experiences in their everyday life. It could be said that the fieldwork is an essential part in the science course, because it gives students the opportunity to explore the science and to study it.

**Previous research**

This study is based on research about students’ learning in physics, the use of scientific methods and students’ difficulties in the problem solving process.

**Outdoor science**

Science education could be performed outdoors to introduce the scientific methods for the students (Slingsby, 2006), and research (Amos & Riess, 2011; Popov, 2006; Popov, 2008) showed that outdoor science can have advantages in comparison with the traditional classroom physics education.

First of all, research showed that students perceive physics mainly as applied mathematics with limited connection to everyday life, and physics could normally be associated with memorizing formulas for problem solving. As a result, students have difficulties to find connections between their own experience of reality and models of physical phenomena described by formulas, and they also have difficulties to construct physics models (Popov & Engh, 2007). In addition, Benckert & Pettersson (2008) elucidate that many students pass Swedish physics courses without conceptual understanding of physics.
An outdoor physics approach has been developed at Umeå University in Sweden, and the focus was to develop inquiry based learning in outdoor environments.

The general goals of the project were defined as:

- To increase students’ interest and motivation to study physics
- To provide opportunities for learning authentic ways of knowledge acquisition
- To facilitate the understanding of the nature of science
- To provide opportunity for students to be more interactive with the learning process (Popov, 2005, p. 1).

Furthermore, Popov (2008) assumed outdoor activities could allow better acquisition of knowledge among students, and teaching physics outdoors can give students the opportunity to investigate phenomena in their natural settings. By comparison, excursions and activities in natural surroundings are popular, but they seldom include physics topics. However, physics teaching placed in natural settings can bring a number of pedagogical advantages and will demand a more open inquiry approach to work (Popov, 2006), and different methods can be used in the outdoor physics approach:

- Play and learn in the open air
- Predict – Observe – Control – Explain
- Prove through action and construction
- Explore authentic problems (Popov & Engh, 2007, p. 22)

The outdoor physics approach gives students opportunity to investigate authentic problems and practice scientific methods. It is necessary to formulate solvable physics problems and to adapt appropriate model with theoretical base, and end up with a solution by designing and performing suitable experiments (Popov, 2006; Popov, 2008). For example, the experimental problems demand preliminarily definition of what to be measured. Furthermore, knowledge of basic physics is necessary in exploration of authentic problems, because students need to depart from known laws of physics and learn to work in real situations (Popov, 2008).

In the United Kingdom, the Government launched The Learning Outside the Classroom Manifesto in 2006 as a way of encouraging education beyond the classroom. Ofsted (Office for Standards in Education, Children’s Services and Skills) is a government department that inspects and regulates institutions in England, and can be described as the equivalent to the Swedish School Inspectorate. According to Ofsted (2008), the Government had placed increased emphasis on activities by this manifesto, activities such as residential visits, field studies, investigations conducted in the local area, sporting events.

Evidence indicated that good quality learning outside the classroom added value to classroom learning. The learning outside the classroom has the opportunity to create deeper understanding of concepts among the students, because it can be difficult to use classroom methods alone to teach those concepts effectively. Furthermore, students can achieve better general and subject-based knowledge, because experienced real situations can raise the achievement in the work with the different subjects. The learning outside the classroom also creates opportunities for the students to develop better personal and social skills, and to develop problem solving skills and cooperation (Department of Education, 2006).

Research and evaluation of the approach of learning outside the classroom has found that the outdoor activities can contribute to students’ learning in different areas. For example, the learning outdoor approach contributed to socially deprived students’ development of teamwork skills and it helped the students to build relationships. Furthermore, the students did
make cognitive gains and the courses did have consequences for students’ environmental behaviors (Amos & Riess, 2011).

All of the schools and colleges surveyed provided exciting, direct and relevant learning activities outside the classroom. Such hands-on activities led to improved outcomes for pupils and students, including better achievement, standards, motivation, personal development and behavior (Ofsted, 2008, p. 4).

As described above, outdoor science can have advantages, but research had also concluded that learning outdoors does not always contribute to better conceptual understanding.

For example, hands-on activities do not necessary contribute to students’ understanding of physical concepts. In this study the students experienced phenomenon like motion and force in amusement park rides, and their knowledge were compared to students who had received traditional teaching about the same concepts. The study argued that there was no clear indication that the students achieved better conceptual understanding when they bodily experienced phenomenon in comparison with traditional teaching (Olsson, 2007).

Open problem solving strategies

The outdoor physics approach broadly uses open-ended authentic problems, and hence, it is necessary to classify problems and find suitable problem solving strategies for open-ended problems.

First of all, problems can be classified with three variables; data, method and goal. The fewer variables that are known to the solver the more open the problem will be (Reid & Yang, 2002A) and therefore, open-ended problems will have a variety of solutions and options of different solving methods are possible.

Problem solving can be seen an essential part of physics learning and usually students solve end-of-chapter problems, where most of the problems are constructed with the aim to find a suitable formula and then apply given numerical values into that formula (Benckert & Pettersson, 2008). It could be said that the solver know all three variables in the end-of-chapter problems, and therefore, the problems can be categorized as closed problems.

It can be described that students perceive physics as applied mathematics, and therefore, they seldom use conceptual knowledge of physics to carefully analyze the problem situation before they start to use algorithmic methods to solve the problem. A common method for students to approach a physics problem is to use algebraic and numerical solutions to manipulate the equations, which they hope will end up with a correct combination so they can find the numerical answer. Furthermore, when the students have found the numerical answer they are usually satisfied, and therefore they rarely check if their answer is plausible (Heller, P. Keith, R. & Anderson, S, 1990). This problem solving strategy agreed with my own experiences in the upper secondary school. The final step was to compare the gained answer with the numerical answer provided by the textbook to establish if the answers matched.

In conclusion, students’ problem solving behavior is understandable but does not enhance learning in physics. However, students will probably be better problem solver if they can adapt standardized problem solving strategies (Benckert & Pettersson, 2008).

Byun, Ha & Lee (2008) have developed a problem solving strategy and the purpose of the model was to help students to solve problems with a problem solving model. The model should also help teachers and students to identify which step caused difficulty in the problem solving process. The different steps were Visualizing, Knowing, Finding, Planning, Execution and Checking. Furthermore, the study determined specific difficulties in a given gap, and it also investigated the cause of the difficulties, because little research has been done about
student difficulty in the problem solving process. The study concluded that the most difficult step was the executing step, and the source was lack of mathematical skills. The second most difficult step was the planning step, and the source was lack of knowledge for solving a specific problem. Moreover, the difficulty in the planning and execution steps increased when the difficulty of the problems increased. On the other hand, a minor part of the students had difficulty with the three initial steps (Visualizing, Knowing and Finding), and the source was determined to be lack of understanding of the situation in the problem. In addition, Reid & Yang (2002A) argued that when students try to solve a problem the first step is to find and understand the problem, and if the students are not successful in this step they will not be able to solve the problem.

In a similar way, it can be argued that students have difficulties to solve open-ended problems because they are not familiar with this type of problems (Elmqvist & Jönsson, 2002). In this thesis the result suggested that when it was necessary to use imagination, and sometimes assumptions, students had difficulties to solve problems. The study used authentic photographs that were used to present situations that involved physics, and the upper secondary level students should calculate different values of physical concepts. The problems should be solved by using information that could be found in the photographs, and the students were encouraged to use books as resource, and also to perform estimations when they found it necessary. Students’ solutions of the problems indicated difficulties to explain if their solutions consisted of estimations or accurate values. Furthermore, the students asked if their solutions were correct or acceptable, which can be seen as they were not familiar to work with this type of problem. In conclusion, the authors argued that the reason to this behavior was that the students were unfamiliar to work with this type of problems.

A survey from the Swedish Agency of Education concluded that students’ problem solving behavior can be attributed to students’ difficulties to think critically, to be creative and to perform independent work, because they are used to get well-structured and closed problems where the teachers already have done the coarse planning. Therefore, students can have problems to formulate detail and well-confined questions when they perform studies, and they can experience difficulty to apply their results to reinforce their arguments and conclusions (Skolverket, 1996).

Reid & Yang (2002B) have studied chemistry students in age 14-17 years to gain insights into the ways students solved open-ended problems. According to the students in the study, a chemistry problem does always have one correct answer, and therefore the study tried to discover the process in students’ problem solving. The conclusion from the study was that it was necessary for the student to know key pieces of information to be able to solve the problem, and if the student had difficulty to solve the problem the cause was absence of these key pieces. Furthermore, students could handle formulas but they did not understand the representation of the formulas, and the lack of clear conceptual understanding caused considerable confusion among students.

Similarly, misconceptions among students can also be found when they study physics. However, these should not be considered as firmly held misconceptions but rather as a sign of students not having coherent frameworks which results in different misconceptions in different contexts (Benckert & Pettersson, 2008). Furthermore, other terms than misconception has been used to describe the knowledge which students bring to science classrooms. For example, terms like alternative framework, preconceptions, personal models of reality and intuitive theories has been defined in the study of conceptual understanding. There are characteristics of alternative conceptions that have appeared in the literature, and some of them are:
• Students hold alternative conceptions about the most natural phenomenon when they come to formal science instructions, and these concepts are not always in agreement with scientific explanations.

• Students’ alternative conceptions interact with scientific concepts that are presented during formal science instruction, and the interaction can appear in unpredictable ways, and therefore produce unintended learning outcomes.

• Students can hold contradictory conceptions at the same time. For example, one conception can be used to describe experienced natural phenomenon, and the other one can be used to give a different answer about the same natural phenomenon in the scientific classroom (Wessel, 1998).

Theoretical Framework

My previous experiences of studying physics and issues raised by educational evaluators (Skolinspektionen, 2010) and researchers (Heller et al, 1990) revealed the problems concerning methods of students’ problem solving. It can be said that the students solve physics problems algorithmically, even though curriculum for the non-compulsory school system (Skolverket, 2006) stressed that students should practice scientific ways of thinking and working.

Scientific inquiry

It is generally accepted that physics education should provide learning experiences and knowledge essential for developing a scientific understanding of the natural world. Furthermore, students are expected to master a set of inquiry-related skills (e.g. problem solving, investigation techniques) and develop understandings about inquiry.

The book Science for All Americans is a result from a project designed to help all Americans to become literate in mathematics, science and technology. The book declares that scientists do not always follow fixed set of steps, because no one path leads them foolproof to scientific knowledge. However, everyone can exercise certain features of science about matters of interest in everyday life, because those features give a distinctive character as mode of inquiry (American Association for the Advancement of Science, 1990).

What Successful Science Teachers Do is a resource that encompasses methods, practices, and classroom management strategies and it defines ‘scientific inquiry’ in the following way:

Scientists use their background knowledge of principles, concepts and theories, along with the scientific process skills, to construct explanations for natural phenomena to allow them to understand the natural world. This is known as ‘science inquiry’ (Cheyne, M, Glasgoq, N.A., Yerrick, R.K., 2010, p. 48)

In the school context scientific inquiry can be partly ‘translated’ through the concept of ‘scientific literacy’.

OECD/PISA defines ‘scientific literacy’ as follows:

Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity (OECD 2003, p. 133)

The term ‘scientific literacy’ can be seen congruent with that the physics education should provide learning experiences and knowledge essential for developing a scientific understanding of the world. Scientific inquiry can be exercised in practical/laboratory activity in a specific context. A number of science learning goals can be attributed to laboratory experiences, and those are:
• Enhancing mastery of subject matter
• Developing scientific reasoning
• Understanding the complexity and ambiguity of empirical work
• Developing practical skills
• Understanding the nature of science
• Cultivating interest in science and interest in learning science
• Developing teamwork abilities (National Research Council, 2005, p. 3)

It can be said that inquiry learning is a form of active learning, where progress is assessed by how well students develop experimental and analytical skills rather than how much knowledge they possess.

Furthermore, Banchi & Bell (2008) suggested that there are four levels of inquiry-based learning in science education.

1. **Confirmation inquiry**
   At the first and lowest level of inquiry the students are provided with the research questions and the method. The result is known in advance.

2. **Structured inquiry**
   At the second level the students are provided with the research questions and the method. The difference between this level and the previous one is that in this level the students produce explanations that are supported by their collected data.

3. **Guided inquiry**
   At the third level the students are provided with the research questions and they need to design the method. Similarly to the previous level the students should produce explanations that are supported by their collected data.

4. **Open inquiry**
   At the third and highest level of inquiry the students are provided with neither the research question nor the method. The students need to derive the research questions, and design suitable experimental setup to test their questions.

It can be said that a characteristic of inquiry-learning is that the students are provided with a research question, and not a statement in their studying of physics. This procedure can allow the students to search for information and be responsible for their own learning with help of teacher’s guidance.

The outdoor physics approach has been developed in Umeå University with aim to motivate and challenge students in thinking physics by using authentic problems (Popov, 2008), and therefore, the approach has the potential to contribute to students’ development of scientific thinking and problem solving skills. Authentic problems can be defined as tasks without beforehand known answers and for these tasks ways of solutions and answers can vary with changing environmental circumstances (Popov, 2008). Hence, authentic problems can be important in the studying of physics to be able to understand the nature of science, because students face situations of genuine inquiry where they have to make decisions about different elements of inquiry. Furthermore, in the outdoor environment there are no predefined experimental settings, and no predefined stages in the data collection and analysis.

It can be argued that most physical phenomena occur outside the classroom, and therefore, the students should be in the environment they are studying. Furthermore, it can also be argued that classroom-based laboratory can no longer be seen as the only option, because in this
teaching method the phenomena are put out of their ‘natural’ context (Renkl, 2001). Learning in outdoor context has been performed and evaluated, and it showed that students did improve their abilities in different areas, for example see Amos & Riess (2011) and Ofsted (2008). However, the learning environment has mostly been in the form of fieldtrips. Out-of-classroom learning can be systematically organized in the surroundings of the school and provide students with the opportunity to work with open-ended problems.

In other words, the surroundings of the school buildings can be seen as the ‘classroom’ for students’ work with open-ended problems. Furthermore, this ‘classroom’ can provide students with the opportunity to study physical phenomena in their natural context, and also to develop their scientific skills.

**Role of Previous knowledge**

*The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly* (Ausubel, 1968, p. vi).

It can be said that inquiry learning emphasizes constructivist ideas of learning, because constructivism is a theory that argues that humans generate knowledge and meaning from an interaction between their experiences and their ideas (Ekstig, 1990). An article written by the Southwest Educational Development Laboratory described that constructivism states that learning is an active, contextualized process of constructing knowledge. Furthermore, constructivism assumes that all knowledge is constructed from the learner’s previous knowledge, regardless of how one is taught. Therefore, it can be said that listening to a lecture involves active attempts to construct new knowledge (Classroom Compass, 1994). Knowledge is formed by the process of combining experience and previous learning with ideas presented which cause disequilibrium for the learner, and when this happens the learner is forced to modify his sets of beliefs. (Ekstig, 1990).

A constructivist theorist who claimed that meaningful learning is opposed to rote memorization was David Ausubel (Ekstig, 1990), whom I cited in the beginning of this section.

Students’ previous knowledge and experience are also important to consider in their development of scientific skills. Scientific ways of thinking and working can be interpreted as constructing ideas and developing skills from experience of physical phenomena. Furthermore, Vygosky (1978) argued that every student has a previous history of learning and that school learning introduces something fundamentally new into the student’s development. For example, students begin to study arithmetic in school, but long beforehand they have some experience with quantity. Consequently, the students have their own construction of arithmetic, which might conflict the proper mathematical definition of the term. Therefore, it can be said that students’ previous knowledge and experiences can contribute to their development of scientific skills, and their ability to perform scientific inquiry.

**Defining Problem Solving Strategy**

Scientific inquiry can be related to a problem solving strategy with no general identified steps in the process, because the different steps in the inquiry can be depended on the investigations and its context. One can say that scientific inquiry requires some sort of problem solving strategy. Previous research has found that students may need guidance in the problem solving process (Benckert & Pettersson, 2008; Byun et al, 2008). My study originated from a problem solving strategy that has been developed in relation to context-rich problems, and therefore, a description of context-rich problem will now follow:
Context-rich problems are designed to focus student’s attention on the need to use their conceptual knowledge of physics to qualitatively analyze a problem before beginning to manipulate equations.

... In addition, they may have one or more of the following characteristics in common with real-world problems:

1. The problem statement does not always explicitly identify the unknown variable;
2. More information may be available than is needed to solve the problem; or
3. Information may be missing but can easily be estimated or is ‘common knowledge’;
4. Reasonable assumptions may need to be made to solve the problem (Heller et al, 1990, p. 629-630).

Moreover, the research (Heller et al, 1990, p. 630) introduced a five-step problem solving strategy for the students to follow when they worked with context-rich problems:

1. Visualize the problem
2. Describe the problem in physics terms
3. Plan the solution
4. Execute the plan
5. Check and evaluate

Descriptions about the different steps will now be presented, and in some steps the connection to laboratory work will also be shown. The first step in the problem solving strategy is to translate the problem statement into a visual and verbal understanding of the problem situation. This can be done by making sketches of the situation, and to identify the known and unknown variables in the problem. Furthermore, it is possible to restate the question to be able to understand it, and the step can also include identifying a general approach to the problem, which can involve physics concepts and principles that are appropriate for the problem situation.

When the solver has a visual and verbal understanding of the problem situation, the next step is to translate this understanding into a physical representation of the problem. This step requires the students to use their qualitative understanding of physics concepts and principles to analyze and represent the problem in physics terms.

The third step in the problem solving strategy is to translate the physics description into an appropriate mathematical representation of the problem, which can consist of equations and relationships. Furthermore, in laboratory work this step can also include the design of the experimental setup, which declares how the students should collect data and what resources they need to use.

When the students had planned the solution the next step is to execute their plan, which involves the use of mathematical rules and the collection of data.

After the execution of the plan the students have one last step to perform, which is to check and evaluate their results. In this step the students need to evaluate the reasonableness of their results, and in laboratory work this step can also include evaluation of the design and execution of the experimental setup. Furthermore, possible contributions from simplifications and sources of error can be evaluated in this step.

As described earlier, scientific inquiry does not have a fixed set of steps that scientists always follow, and therefore, different scientific methods can be performed which depend on the contexts and situations. The five-step problem solving strategy described above presents a
didactical tool that can be used to solve physics problems in a scientific manner. However, the strategy needs some modification before it can be adapted to authentic problems. In these problems the students often need to formulate solvable problems and in some cases the elimination of irrelevant data is necessarily (Popov, 2008). Therefore, it is necessary for me to introduce a Step 0 in the problem solving strategy, where students need to identify and formulate solvable problem from an open-ended authentic problem. As a result, I suggest six steps in the problem solving strategy:

0. Identify and formulate ‘solvable’ problem
1. Visualize the problem
2. Describe the problem in physics terms
3. Plan the solution
4. Execute the plan
5. Check and evaluate

This didactical tool of open inquiry strategy will be used in my thesis work for designing the study and analysis of the results.

Objectives and research questions

The study was designed to increase learning activity among students in their physics lessons, where the scientific inquiry was the method of use. The learning activity, for analytical purposes, could be separated into two parts:

- **Conceptualizing activity** – students needed to formulate and design their own studies
- **Practical activity** – students needed to perform their own studies in practice. For instance, they were required to construct experimental setups and perform practical measurements.

Scientific ways of working and thinking require the students to work as scientists, which imply that the student should study phenomena in their everyday life (Slingsby, 2006). To be able to study these phenomena the students can with advantage experience physics in natural settings (Olsson, 2007; Popov, 2006; Popov, 2008, Popov & Engh, 2007). Therefore, the tasks in this study were chosen so they could not only be performed inside of the classroom, because relevant objects may only be found outside the classroom. It could be said that the tasks were context-bound, and the reason was that it gave the students the opportunity to investigate authentic problems and to practice scientific methods.

The study aimed to investigate how technical program students approach open-ended problems, difficulties the students experienced in their work, and also tried to explain the reason for this.

Furthermore, students might need varying degree of guidance in the problem solving process, and therefore, it was necessary to study what types of guidance the students required in their work with the open-ended problems.

The research questions can be stated as follows:

- How often does teacher’s activity include work with open questions and open-ended problems?
- How do technical program students prepare to work with open-ended problems?
- What difficulties do students reveal in the different steps of the problem solving process?
- Which levels of guidance do the students require in their work with open-ended problems?
Methodology

There exist several ways of doing educational research, where each strategy can have distinctive advantages and disadvantages. Therefore, the choice of research strategy depends on the type of research question, and the control the researcher has over actual behavioral events and the focus on contemporary as opposed to historical phenomena (Yin, 2003). As a general methodological framework I used case study methodology.

Case Study

Case study design is particularly suited to situations where it can be impossible to separate the phenomenon’s variables from their contexts. To be more specific, case study is a suitable research strategy to use when the nature of the research questions is how and why, and when the study investigates a contemporary phenomenon within its real-life context. Other criteria for case study research are that the boundaries between the phenomenon and context are not obvious and multiple sources of evidence are used (Merriam, 1994; Yin, 2003).

The case study seeks holistic description and explanations of a bounded system, which can be identified as the focus of the investigation, and it is denoted as a case (Merriam, 1994). Furthermore, an attempt to define a case is:

*a unit of human activity embedded in the real world which can only be studied or understood in context* (Gillham, 2003, p. 1)

Case study focuses on one specific situation or phenomenon with the purpose to concentrate attention on how the case study group confronts specific problems. It can be said that the study tries to give a holistic view of the situation. Furthermore, case studies often include as many variables as possible to describe their interactions and analyze the situations. It can also be said that case studies are based on inductive reasoning, because emerged generalizations, concepts, or hypotheses from the data are grounded in the context itself. Therefore, case studies can reveal discovery of new relationships, concepts and understanding, rather than verification or predetermined hypotheses (Merriam, 1994).

It can be argued that case study is a ‘naturalistic’ investigation, because the study investigates the phenomenon in its naturalistic setting (Cousin, 2005; Stensmo, 2002). For example, students’ actions during a physics lesson cannot be studied during a lesson in another school subject. Hence, the study needs to be performed during an authentic physics lesson.

The case study uses triangulation, which is the use of multiple methods of data collection. For example, it can be said that the triangulation combines dissimilar methods as interviews, observations, and physical evidence to study the same situation or phenomenon (Gillham, 2000, Merriam, 1994; Yin, 2003).

Sample and Context of the Study

The case study group was selected from a municipal upper secondary school in the county of Västerbotten, and it consisted of students in their second year of a Technology Program. The study was performed in the Physics A course together with the course coordinator, who also was a participant in the case study group.

The study group consisted of 21 students and the male course coordinator, who has worked over 10 years as a physics teacher at upper secondary school level. Furthermore, the students in the case study group were in the age of 17 years, where 20 of the students were males and one was female.
This specific case study group was selected with the argument that their education should prepare them to work with technical problems, which can be argued to require open-problem solving skills. For example, the program objectives describe that the students should develop communication and actions skills that it required to be able identify and solve in practice. The students should develop abilities to find connections between theories and technology applications, and they should also plan and carry out experiments and field studies, conduct observations in an objective and systematic manner and to interpret and report results (Skolverket, 2000).

The participants were informed during the first lesson of the course about the ethical guidelines for educational research (BERA, 2011), which states that the contribution is voluntary, and the participant will be anonymous and has the right to withdraw his or her participation. In this study the students had the possibility to choose their participation to be audio recorded during their activities and interviews, and every student approved to be audio recorded. This means that if a student did not participate in a lesson it was because of other reasons than the resistance to be audio recorded.

The teacher’s plan of the physics lessons included a separation of the class into two groups, and those groups were also used in this study. The separation of the class was performed on the basis of the students’ mathematical knowledge and skills. The group with the lower mathematical knowledge and skills consisted of ten students where one of the students was female, and the group is addressed as Group A in this study. The group with the higher mathematical knowledge and skills consisted of eleven males, and the group is addressed as Group B in this study. This separation of the students into two groups also included they carried out the tasks at different times.

The students performed the tasks in subgroups that consisted of 2-4 students depending on the number of participants at each lesson. The subgroups in Group A were labeled with numbers, e.g. A1, A2, A3, and so forth, and the same pattern was used for Group B. The students had the opportunity to create the subgroup constellations by themselves, and if it was necessary the teacher had the responsibility to create the subgroups. Furthermore, the study of the students’ work with open-ended problems were performed during a 10-week period, where the students worked with the tasks during a lesson every third week. The time length of every lesson was 80 minutes.

**Inquiry Tools**

Following the planning made by the teacher, I could choose between two topics for this study, classical mechanics and energy. The topic of classical mechanics was chosen after a review of accessible tasks in the outdoor physics approach that have been already developed and can be found at their webpage (http://outdoorphysics.educ.umu.se).

The study was performed during a Physics A course that was compulsory for the students and it was an introductory course in physics. The area the students studied during the period of this study was classical mechanics, which consisted of concepts and theories about mass, motion and pressure.

Furthermore, I agreed with the teacher to suggest the three context-based tasks could be part of the regular physics lessons. The tasks were time scheduled and compulsory for the students to perform, but their work with the tasks were not graded. The times of events for the tasks were decided by the teacher, and the events were accommodated after the plan of the physics course so the students should have gained sufficient knowledge for the tasks that required it.
**Task description**

The following open-ended tasks were offered to the students:

*Task 1:* The aim of the task was to introduce the students to the outdoor physics approach, which means they worked with an open-ended problem, and the solutions methods depended on the students’ interpretation of the problem. The students were asked to study the following question:

*Which parameters affect how objects fall?*

*Task 2:* The aim of the task was to give the students opportunity to apply the theoretical knowledge they have acquired during the physics lessons. The students were asked to study the following question:

*Determine the mass of a specific big scale object*  
(Picture of the object can be found in the *Results*)

*Task 3:* The aim of the task was to let the students to study how the pressure was affected by the change of mass and contact surface. In other words, the task created opportunities for the students to make decisions about different scenarios for the same study. The students were asked to answer the following question:

*What provides largest pressure on the ground, you or a stone?*

**Procedure of task introduction**

Classroom-based instructions for the tasks were performed, where the purpose was to introduce the task for students, and to provide them with essential information and hints. Furthermore, every task was introduced during a regular physics lesson the week before the performance of it. During the introductions the students were encouraged to make preparations in the form of formulating specific questions they could investigate and possible methods they could use. The students were also encouraged to make preparations in the form of access to resources. During the introductions I stressed the students about the necessity to ask for resources in advance in the case they did not have access to them by themselves.

Moreover, the students received contact information to me, and they were also encouraged to ask questions about the tasks with the argument that it should not be any ambiguity about the tasks among them. It could be said that the responsibility where transferred from the teacher to the students, because the students did have an active role in the form of preparations and actions to approach the open-ended tasks.

The introduction of Task 1 included a session where the students were encouraged to write down their answer to the question by themselves, and then the answers were collected. The reason for this action was to encourage the students to start working with the task at once and also to give them the opportunity to construct ideas that they could test in their experiments.

The reason why this action did not take part during the introductions of Task 2 and Task 3 is that the objects of interest were predetermined in these tasks. In comparison with the question in Task 1, where the question did not ask about a specified object or item. For example, the question of Task 3 required the students to use a ‘stone’, and hence, the object was specified. However, the question did not provide information of which type of stone the students was required to use, and therefore, the students did still have the opportunity to influence the option of suitable stone in their experiments.
Methods of Data Collection

The study used qualitative research approach and three methods of data collection during the performance of the study. The methods were determination of teacher’s activity, audio recording of the students’ actions and interviews with students. Furthermore, information about the chronological sequence will also be presented.

Teacher

The data collection of the teacher’s activity included three phases:

1. Observation of teacher’s use of open questions
2. Quantitative measurement of teacher’s questions
3. Interview with the teacher

The first phase were conducted as observations of what kind of questions the teacher asked the students during the physics lessons, and the phase revealed information about how to categorize them. The observations took part in the classroom during regular lessons in the physics course and the data were collected by audio recording.

The second phase used the categorization of the questions to quantitatively investigate the distribution of the questions. Data was collected by audio recording so the categorization of the questions could be done carefully afterwards.

The third phase consisted of an audio recorded interview with the teacher, where the teacher had been informed about the topics of the interview in advance. The interviews followed the guideline presented by Johansson & Svedner (2006), which means the interviews were performed by using open questions. A description of the interview and related topics can be found in the appendix.

Students

The research tool for the data collection of students’ activity during their work with the tasks can be described as participant observation, because my role can be described to be a teacher. For example, I had the same role as the original teacher, which was to help the students when they needed it or asked for it. Furthermore, the data about every subgroup’s activity and actions were collected by audio recording.

Interviews with two students were performed in the same manner as with the teacher, in other words, the interviews were performed after their work with the three tasks was done. Furthermore, the interviews took place in the school cafeteria during school time, and the time and place were chosen by the students. Furthermore, each respondent were informed in advance about the topics of the interview, the estimated length of the interview, and their anonymity. The interviews followed the guideline presented by Johansson & Svedner (2006), which means the interviews were performed by using open questions. Furthermore, possible subjects of the topics were created, and the reason to this design was that the questions in each interview could vary depending of the respondents’ answers and opinions. A description of the interview and related topics can be found in the appendix.
Chronological sequence of data collection

As described earlier, the study was performed over a 10-week period, and the chronological sequence of the different data collections can be seen in Table 1.

Table 1. Chronological sequence of data collection

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Activity</th>
<th>Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regular lesson</td>
<td>Teacher’s activity – Phase 1</td>
</tr>
<tr>
<td></td>
<td>Introduction to Task 1 – Group B</td>
<td>Student’s answer to Task 1</td>
</tr>
<tr>
<td>2</td>
<td>Regular lesson</td>
<td>Teacher’s activity – Phase 1</td>
</tr>
<tr>
<td></td>
<td>Introduction to Task 1 – Group A</td>
<td>Student’s answer to Task 1</td>
</tr>
<tr>
<td>3</td>
<td>Task 1 – Group B</td>
<td>Audio recording of student’s actions</td>
</tr>
<tr>
<td>4</td>
<td>Task 1 – Group A</td>
<td>Audio recording of student’s actions</td>
</tr>
<tr>
<td>5</td>
<td>Regular lesson</td>
<td>Teacher’s activity – Phase 2</td>
</tr>
<tr>
<td></td>
<td>Introduction to Task 2 – Both group</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Task 2 – Group B</td>
<td>Audio recording of student’s actions</td>
</tr>
<tr>
<td>7</td>
<td>Task 2 – Group A</td>
<td>Audio recording of student’s actions</td>
</tr>
<tr>
<td>8</td>
<td>Regular lesson</td>
<td>Teacher’s activity – Phase 2</td>
</tr>
<tr>
<td></td>
<td>Introduction to Task 3 – Both group</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Task 3 – Group B</td>
<td>Audio recording of student’s actions</td>
</tr>
<tr>
<td>10</td>
<td>Task 3 – Group A</td>
<td>Audio recording of student’s actions</td>
</tr>
<tr>
<td>11</td>
<td>Interview Teacher</td>
<td>Teacher’s activity – Phase 2</td>
</tr>
<tr>
<td>12</td>
<td>Interview Student 1</td>
<td>Students’ actions</td>
</tr>
<tr>
<td></td>
<td>Interview Student 2</td>
<td>Students’ actions</td>
</tr>
</tbody>
</table>

Table 1 shows the chronological sequence of the data collection. It describes in which order the different activities occurred and what data that was collected during each activity. Activities with the same number were performed during the same lesson, besides the interviews with the students because those were performed individually and consecutively. Regular lesson is traditional physics lesson hold by the teacher and where this study did not have any influence or contribution, which means the lesson was not based on any task.
Method of Data Analysis

Information about teacher’s activity and students’ actions were collected, and will be analyzed with respect to the teacher’s activity, students’ work with open-ended problems and interviews with students.

Teacher

The analysis of the data from observations and teacher interview was based on the role of previous knowledge that has been described in the theoretical framework for this study.

In the analysis of the observation the questions were categorized as open or closed, and if the responses were due to factual knowledge or understanding.

- Open question – several different answer are possible
- Closed question – one specific answer is possible
- Question probing for factual knowledge – answer with known fact is required
- Question probing for conceptual understanding – answer with explanation is required

The research tool of the two phases described above was naturalistic observation, where my observation did not interfere with the study groups’ activities in their natural context. For example, I did not participate in the conversations between the students and the teacher.

In the second phase every question asked by the teacher was transcribed and then categorized depending on their formulation and substance.

The third phase consisted of an interview with the teacher with the purpose to find information about aspects that could contribute to students’ previous knowledge and experiences in physics. The interview was transcribed in detail and the findings were distinguished with respect to their relation to the traditional lessons or laboratory work.

Students

The naturalistic research paradigm of Lincoln & Guba (1985) was followed in the analysis of the students’ actions, where data accumulated in the field thus must be analyzed inductively in order to define local working hypotheses or questions that could be followed up. Inductive analysis to interpret specific social situations was used. All situations considered relevant to the problem under study were identified in the audio records and interviews and grouped into categories. Relevant situations can be described as when students had difficulties to proceed their work, or when they revealed possible misconceptions that contributed to their decision-making. The audio recordings from students’ work with the tasks were summarized, and part of the audio recording that revealed interesting findings were transcribed and carefully reviewed.

The situations analyzed correspond to process of solving the problems by groups of students assisted by the teacher. Assistance involved interaction of the teacher with the group, rather than with individual students, and the analysis focused on what the group, as a whole, was capable of doing. Assistance was provided with the aim of enabling the group to perform new form of tasks, where it could be multiple answers and solution methods to the same problem.

Furthermore, the categorized situations were analyzed with respect to the ‘six step model’ to be able to investigate how technical program students approached open-ended problems, and which difficulties they experienced in relation to scientific ways of thinking and working.

In a similar way, the categorized situations were also analyzed to find what different types of guidance the students required in their work with the open-ended problems.
The interviews with the students can be seen as compliments to the observations of the actions in their work with the tasks, where the purpose of the interviews was to discover and identify aspects that could not be explained by their actions and activities. For example, possible actions from the students that were not audio recorded and still could give data to answer the research questions. The two interviews were transcribed in detail.

Transcriptions and conversations are indicated in *italics* and they have been translated into English. The collected data in this study has been translated from Swedish to English, which includes students’ conversations in their performance of the tasks, interviews with teacher and students, articles and other used information that was written in Swedish. Furthermore, the distribution of gender in the study group made it difficult to make any gender comparison, and hence, students in this report will be discussed regardless their gender. Moreover, my own participation was active during the students’ work with the tasks, and therefore my representation is defined to be *teacher* in this report.
Results

The results from the study will be presented under five headings:

- Teacher’s activity based on observations and interview
- Task 1: Study of falling objects
- Task 2: Determination of an object’s mass
- Task 3: Study of pressure between solid objects
- Students’ experiences

First point was based on the teacher’s activity, and the result will be presented with respect to the findings from observations of teacher’s activity in the classroom and interview with the teacher. It was important to present the tasks separately, as each of them was connected to a specific context. According to case study methodology this might highlight specific characteristics of the case. The last point was based on interviews with students about their experiences, where focus was about the preparatory work in form of formulating solvable problems, designing experimental setups and finding resources.

**Teacher’s activity based on observations and teacher interview**

The summative presentation of the teacher’s questions during two lessons can be found in Table 2.

<table>
<thead>
<tr>
<th>Table 2. Teacher’s question to the students</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lesson 1</strong></td>
</tr>
<tr>
<td>Total number of questions</td>
</tr>
<tr>
<td>Open questions</td>
</tr>
<tr>
<td>Fact</td>
</tr>
<tr>
<td>Explanation</td>
</tr>
<tr>
<td>Closed questions</td>
</tr>
<tr>
<td>Fact</td>
</tr>
<tr>
<td>Explanation</td>
</tr>
</tbody>
</table>

Table 2 shows the total number of subject related questions the teacher asked the students during the two lessons. These questions were related to the topic of the lessons. The table also shows the number of questions that were open and closed, and how many of them were due to answers with respect to fact and explanation.

The interview with the teacher revealed information about his planning of the physics lessons, the experiments and problem solving guidance, which will now be presented.

In his planning of the physics lessons the teacher wanted to give the students the opportunity to solve problems at the end of each lesson, and if he knew about well-performed demonstrations he often used them to illustrate or describe concepts. Furthermore, if the
teacher knew about an experiment that was appropriate for the students to perform he preferred to let them do that experiment before they had been taught any relating theory.

According to the teacher, the experiments used traditional instructions, and step-by-step instruction was used in many experiments. Furthermore, the teacher did not believe the experiments could enhance the students’ understanding of physics concepts, because he had experienced that sometimes the students understood less after they had performed an experiment than before the experimental session.

_They do not see any connection [between the experiment and related theory], but the purpose of it is of course that they should see the connection. [...] Sometimes I think that I let them perform an experiment because they must do it, and that they should be more familiar to perform experiments. The awareness of the connection [between the experiment and related theory] needs to come later, because they have never done experiments before and they need to start sometime._

Furthermore, the teacher explained that the students were able to perform experiments with step-by-step guidance better than experiments that included less detailed instructions.

As described above, students usually get the opportunity to solve problems during the lessons, and if the students needed help the teacher explained that he wanted to help the students by explaining the problem in general terms and by giving hints like ‘have you thought about that’. However, the procedure of guidance depended on which student he helped, and mostly it was necessary to explain the solving procedure in detail for the students.

In the end of the discussion with the teacher he revealed the information that a couple of the students adapted knowledge gained from their work during the tasks in later lessons in the course.

**Task 1: Study of falling objects**

**Instructional activity**

The introduction of Task 1 was given to Group A and Group B during two separate lessons and the introduction took part in the classroom. The introduction began with the question, _what effects how objects falls_, and the students were encouraged to write down their answer individually. Furthermore, the students were informed that there were no restrictions to the number of answers, and later all answers were collected to be analyzed. Students’ answers can be found in Table 3, and the purpose with the session in the instruction part was two-parted.

First of all, the session gave the students an opportunity to start to think about what problem they wanted to solve, which could be helpful in the preparatory work. The second purpose of the session was to gather information about the students’ answers about the parameters they thought contributed to the fall of the object before they had started to work with it. In other words, the activity would reveal if the students had any preconceptions about the task.
Students’ answers in Table 3 shows that most students thought that gravitation and mass would contribute to the fall, followed by the weight and shape of the object. Furthermore, it needs to be clarified that at the time of this session the students had not gained knowledge from the physics lessons about the difference between an object’s mass and weight.

The students were divided into subgroups before they could start to work with the task. The students in Group A were divided into two subgroups, the first subgroup contained two students and the second subgroup contained three students. In similar way, the students in Group B were divided into two subgroups with three students in each subgroup. In total 11 students participated in the problem solving of the task.
Students’ activities

The students used different hypothesis in comparison with each other, and the methods to use were developed after their hypotheses, and they will now be presented.

Suggested hypothesis and methods of solution

Every subgroup formulated one hypothesis, and in total three different hypotheses were formulated and can be viewed in Table 4.

Table 4. Students’ choice of hypothesis and method

<table>
<thead>
<tr>
<th>Group</th>
<th>Hypothesis and Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A1</td>
<td>Hypothesis 1: The shape of the object affects the free fall</td>
</tr>
<tr>
<td>Group A2</td>
<td>Hypothesis 2: The mass of the object affects the free fall – Method 2</td>
</tr>
<tr>
<td>Group B1</td>
<td>Hypothesis 2: The mass of the object affects the free fall – Method 1</td>
</tr>
<tr>
<td>Group B2</td>
<td>Hypothesis 3: The shape and the mass of the object affect the free fall</td>
</tr>
</tbody>
</table>

Table 4 presents the hypotheses and methods the subgroups used during their work with the task, and in the case where multiple methods were used for the same hypothesis the table also shows which method respective subgroup used in their experimental setup.

The first hypothesis was that the shape of the object affected the fall and the students used a method where they had objects with the same mass and different shapes, and then they dropped them from the same height. Thereafter the students determined if the objects reached the ground simultaneous or not, and the hypothesis was false if the two objects reached the ground simultaneous.

Figure 1 shows an example of two objects with the same mass and different shapes, and in this case there are two A4 paper sheets, which were verified to have the same mass.

Figure 1: Objects with the same mass and different shapes
The second hypothesis was that the mass of the object affected the fall and the students used a method where they had two objects with the same size and shape, but with different masses. The students dropped the objects from the same height to be able to determine which one of the objects reached the ground first, and the hypothesis was false if the two objects reached the ground simultaneously. Furthermore, two different methods to drop the objects were developed to determine if the objects reached the ground simultaneously or not, and the methods will be presented individually.

The first method used two different objects with the same size and shape, but with different masses, and the students dropped them simultaneously from the same height. The sound of the objects when they hit the ground was used to determine if they reached the ground simultaneously or not.

The second method used an empty box to be able to vary the mass of the contents in the box, but still be able to keep the same size and shape of the box. An object with known mass was placed inside the box, and then the box was dropped from a specific height and the time interval was measured between the drop of the box and when it hit the ground. Thereafter the students changed the mass of the objects inside the box and dropped it from the same height again, and also measured the time interval once more. The time intervals were compared to determine if the hypothesis was verified or not.

The third hypothesis was a combination of the two previous presented hypotheses, and it could be said that the hypothesis was that both the shape and the mass of the object could affect the fall. The students used similar approach to what has been described in the second method above, but with the modification that when they changed the mass inside the box they also changed the surface area of the box by using another box with a larger surface area.

Problems and issues identified while working with the task

The problems and issues that have been identified in students’ work with the task were separated into different categories, which now will be presented.

Absence of preparatory work

The students were prepared for the task by answering the question one week before they should design and perform experiments, but regardless of this opportunity the students had not done any further preparatory work, such as formulating ideas or theories they wanted to test or did not bring necessary resources. To illustrate this, a conversation will be presented, where the students in subgroup B2 asked for specific resources during the design of their experimental setup:

Subgroup B2, Task 1

Teacher: How is it going?
Student: We need three cubic-shaped pieces of metal.
Teacher: Ok.
Student: Then we also need pieces of wood that also are rectangular... and we also need cardboard boxes that are in different sizes and weights.
Teacher: Ok, and where can we find that?
Student: Well... cardboard boxes should be easy to find somewhere...

The discussion between the student and teacher revealed information that the students in the subgroup did not do any preparatory work in the case of design the experimental setup and thoughts about necessary resources in advance.
Furthermore, when the subgroup had explained their findings and inferences a discussion about the difficulty of the task aroused:

Teacher: So the task was not too difficult?

Student: No, but the time was too short, and it was difficult to receive consistent data from the drops of the boxes. In the best case scenario we should have used a robot that could perform the drops with high accuracy, but we did not have access to that kind of resource.

Teacher: We have a robot here in the school building that can do that.

Student: Ok… that should have been good to know in advance…

Teacher: Did anyone ask if we had that kind of resource?

Student: No…

The discussion revealed the information that the student had an idea to use a resource that he did not think he had any access to, and he did not ask the teacher about it in advance.

**Formulate solvable problems**

In general, the subgroups had difficulties to formulate solvable problems, because it was necessary to give guidance to every subgroup (expect subgroup B2) in form of leading questions. Furthermore, the task needed to be restated for the subgroups in Group A, and they received instructions to be able to formulate solvable problems. As a result, the students could find out which parameter they wanted to test with help of the guidance. The example below illustrates subgroup B1’s difficulty to formulate a solvable problem.

**Subgroup B1 Task 1**

Student 1: I do not understand anything of this

Student 2: I was not here the last lesson. First, we must know... we need to take an object that we should check how it falls...

Student 1: What parameters affect how an object falls? Size and volume, or mass and volume. Because if the resistance is bigger than the mass, or how much the mass can handle, or... It is like this, if an object falls it creates friction and a force upwards, and if the force upwards is bigger than... if the object is too heavy it will be slow. That is why objects fall with the same speed when they are dropped from the same height in vacuum, regardless if you have one kilogram of iron or a feather. It is really weird, but it is true

[...]

Student 1: I have no idea what to do

Student 2: What more do we know?

Student 1: Nothing. The gravity

Student 2: The gravity makes object fall

Student 2: From which height should we drop the object? From the window, or?

Student 2: What else should we bring up? I have not done any preparations...

Teacher: How is it going?

Student 2: Slowly

Teacher: In which way does it go slowly?

Student 2: I do not know. We do not for sure know what we should do
Teacher: But you have some ideas which parameters affect the falling of the object? Can you give some examples?

Student 1: Gravity

Teacher: You think the gravity affects the fall, how can you test that?

[Student 1 threw a book through the air]

Teacher: How do you know that the gravity affected the book?

Student 1: Because I threw it upwards and it came down again, and therefore something pulled it downwards.

Teacher: Was it just the gravity that affected the book? Can there exist anymore parameters?

Student 2: Mass and volume of the object

Teacher: How can you test that?

Student 2: We use two objects with different sizes

Student 1: And they must have the same mass, otherwise the fall will also depend on the mass

Teacher: You want to test if the volume affects the fall of the object, then you need to figure out how you can perform the experiment so you can make any conclusions from your experiment.

As the discussion revealed, the students had difficulties to formulate a solvable problem. Furthermore, the students did not find any suitable objects for their experiment, and it was necessary for the students to reformulate the problem they wanted to solve. The reformulated problem was to test if the mass of the object affected the fall of it instead of the volume of the object.

Weak knowledge of sources of error

The task was designed to require the students to make decisions about relevant and irrelevant data, and therefore, they needed to take into consideration the possible contribution of sources of error. For example, both subgroups in Group A showed lack of understanding of the possible contribution from sources of error, and this will be illustrated by an example:

Subgroup A2 Task 1

Student 1: The object falls slower for every drop

Teacher: If you only drop if once, are you sure that you receive accurate data?

Student 2: No...

Student 1: It follows the same pattern, because it takes longer time for the object to reach the floor

Teacher: So if you only drop it once, can you then be sure that the data is accurate?

Student 2: No

Teacher: What do you need to change in your experimental setup to know for sure that you get consistent data?

Student 2: We need to do multiple drops for the same situation

Student 1: Maybe you should handle the stop watch?

Student 2: Who should drop the box?
Student 1: You
Student 2: I should drop the box and handle the stop watch at the same time? No...
Teacher: That sounds like a good idea, you can try it.
[...]
Teacher: Now you got 49 ms, the drop before with the same situation you got 30 ms, so which one of the result is more accurate?
Student 2: I do not know... maybe 49 ms...
Teacher: You can do the same drop again to be able to conclude which one of the is most plausible
[...]
Student 2: 55 ms
Teacher: So then it is possible to conclude that the accurate result is closer to 49 ms than to 30 ms

The conversations revealed information that the students did not think about to include the possibility of randomness in their experimental setups, and it was necessary to give advice and instructions before the students could start to do multiple drops of the object for the same scenario. Furthermore, the students in subgroup A2 did not reflect over the contribution the human reaction time could have to their experiment. The same problem was revealed in the work of subgroup A1, because they needed to be informed to use multiple drops to minimize the influence of randomness in their data.

**Difficulty with constant parameters**

In this study the notion of constant parameters were used instead of independent variables, because it was the terminology that was used among the students during their performance of the task. The students showed lack of knowledge to make systematic and consistent measurements when they designed and performed their experimental setups. The example below illustrates subgroup A2’s difficulties to make systematic and consistent measurements:

**Subgroup A2, Task 1**

Student 1: Now you are holding it to high
Teacher: Are you sure that you drop it from the same height?
Student 2: I do not know that.
Teacher: How can you be sure that you always drop it from the same height?
Student 2: I do not know.
Teacher: You need to have a reference point that you know always have the same height, do you know anything in the surrounding that is placed on the same height all the time? You can use that as a reference point and hence you will now that you always drop the box from the same height

The information from the conversation revealed that the students had problems to understand the principle of their experimental setup in the case of keeping the height constant. As a result, the students received contradicting data, which could be caused by the fact that the height varied during the different drops of the object. Furthermore, the students did not take this into consideration without instructions from the teacher.
In a similar way, it was necessary for the teacher to give instructions to subgroup A1 so they could design an experimental setup where the mass should be constant for the different objects. The difficulty was that the students attached a piece of tape to the object when they folded the paper, and the teacher needed to explain for the students that they needed to attach the same length of the piece of tape to every object, because otherwise the mass should not be constant.

In contrast to the other subgroups, the students in subgroup B2 did not have problems to perform the experimental setup, but their design of the experimental setup included two hypotheses. As a result, the students showed lack of understanding of the necessity with constant parameters because they wanted to test two hypotheses simultaneous in their experimental setup, which used two variables to determine if the mass and the surface area of the object affected the fall.

**Difficulty to draw inferences**

Students in subgroup A2 had difficulties to draw any inferences at all of their experiment and data collection, which the example below illustrates:

**Subgroup A2, Task 1**

_Student 1: What is our result?_

_Student 2: Yes... maybe we should calculate how... remove our distance of reaction.... or... what else...?_

_Student 3: I do not know...

_Student 1: What is our conclusion?_

[...]

The discussion between the students in the subgroup revealed information that they had problems to make any inferences at all from their results, and the students needed to answer leading questions from the teacher to be able to make any inferences about their results.

In a similar way, the students in subgroup B2 had difficulties making any clear inferences about their results, but in contrast to the other subgroup the students could make inferences without guidance. However, it revealed to be difficult to verify two hypotheses during the same experimental setup:

_Teacher: What have you done and what are your conclusions?_

_Student: We performed tests to establish if the size and mass of the object contributed to its fall. We had three boxes in different sizes and we added weight into every box and did multiple drops. We found that the added weight did not affect the object’s fall._

_Teacher: Did you use the same size of the area and changed the added weight?_

_Student: No, we changed both the size of the area and the weight of the boxes._

_Teacher: So, what did you find out?_

_Student: We found that the weight of the box did not contribute as much as the air resistance due to the increased size of the box_

According to the student, the relation between the mass and the surface area of the object affected the fall, but they had difficulties to determine if one of the parameters affected the fall or if both contributed to the fall of the object.
Need of Step-by-step guidance

It was necessary to give guidance to both subgroups in Group A in the form of examples and instructions so they could formulate solvable problems and design their experimental setups. In the general case, guidance was not necessary when the students knew what they should do and how they could do it. Furthermore, guidance in the form of hints and leading questions were needed continuously during the students’ work with the problem, because the students showed lack of knowledge and skills to design and perform experimental setups. For example, leading questions were necessary for the students to be able to make inferences about their results and to reflect over the reliability of their results.

Task 2: Determination of an object’s mass

Instructional activity

The introduction of Task 2 was given to the class during a lesson and it took part in the classroom. A picture of the object was shown for the students and they were informed that they should determine the mass of a large-scaled object. Furthermore, the students were encouraged to ask questions and also start to think about how they could approach the problem. For example, advice such as that the term mass of the object could be interpreted in different ways was given to the students. For instance, the mass of the object could be translated as the mass of the object when it was empty or the mass of the object including its contents.

The students in Group A were divided into two subgroups with three students in each group. Similarly, the students in Group B were divided into three subgroups, with three or four students in every subgroup. In total 16 students participated in the problem solving of the task.

Figure 2: The object of interest in the task

The students had the opportunity to choose which one of the objects in Figure 2 they wanted to use in their experimental setup, and the objects were found in the schoolyard.

Students’ activities

The students used two different physical models to approach the problem. The first model was Newton’s laws of motion and the second model was the balance principle. The models and relating methods of measurement will now be presented.
**Newton’s laws of motion**

Newton’s second law of motion states that the force is equal to the mass times the acceleration. This means that if we have an object with a constant mass, the force will be proportional to the acceleration, which can be seen in the formula

\[ F = m \cdot a \]

where \( F \) is the net force, \( m \) is the mass of the object and \( a \) is the object’s acceleration.

Starting from this theoretical knowledge, two methods of measuring were developed and used by the students to determine the acceleration of the object. The two methods will now be presented.

In the first method the object was pushed by a constant force, which created a constant acceleration on the object. The applied force could be measured by the use of a bathroom scale, which made it possible to determine the force in the units of mass. Furthermore, to measure the acceleration it was necessary to identify the initial and final velocity, and also during which time interval the change of velocity occurred. The used method suggested that if the object started from rest the initial velocity would be zero and the final velocity could be determined by using a GPS device, and the time could be measured from the moment object started to move until it reached final velocity.

In the second method the object moved at a constant initial velocity, which means that the friction force and the applied force was the same. The force could be determined by the use of a bathroom scale with the same principle as in the first method. Furthermore, the acceleration could be determined by letting the object move freely, i.e. only the friction force acted on the object and eventually the object would be at rest. The initial and final velocities were known, and by measuring the time interval between the velocities the acceleration could be determined.

**Balance principle**

Students used the principle for a balance scale and constructed a large-scale version in outdoor context, where the unknown mass of the object could be determined when it was in equilibrium with a known mass.

![Figure 3: Balance scale in equilibrium and disequilibrium with different numbers of added objects](image-url)

a) Balance scale in equilibrium – no objects added  
b) Balance scale in disequilibrium – one object added  
c) Balance scale in equilibrium – two objects added
Figure 3 shows three different scenarios with a seesaw, which uses the same principle as a balance scale. First of all, Figure 3a shows the balance scale in equilibrium and at rest, which indicate that it is properly balanced. If a stone is placed at the end of one of the lever arm the mass of the two lever arms will not be equal, and the balance scale would be in disequilibrium, which can be seen in Figure 3b. Furthermore, Figure 3c shows that the balance scale would once again be in equilibrium if another stone is placed at the opposite lever arm. Consequently, if the stones’ center of mass is placed at the same distance from the pivot point the system is in equilibrium, and hence, the mass of the stones can be concluded to be almost equal.

The students constructed their own balance scale from suitable materials, and they placed the object with unknown mass at the end of one of the lever arms. Furthermore, at the other lever arm they placed a bucket, which they put bricks inside until the balance scale was in equilibrium. Thereafter, the mass of the bucket and the bricks were determined by using a bathroom scale.

<table>
<thead>
<tr>
<th>Physical model and method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A1</strong></td>
</tr>
<tr>
<td><strong>Group A2</strong></td>
</tr>
<tr>
<td><strong>Group B1</strong></td>
</tr>
<tr>
<td><strong>Group B2</strong></td>
</tr>
<tr>
<td><strong>Group B3</strong></td>
</tr>
</tbody>
</table>

Table 5 presents the physical models and methods the different subgroups used during their work with the task.

**Problems and issues identified while working with the task**

The problems and issues that have been identified in students’ work with the task were separated into different categories, which will be presented now.

**Absence of preparatory work**

The result of students’ preparatory work showed three levels of preparation, and the first level of preparation can be described as no preparation at all. The two subgroups in Group A did not show any evidence that they have given the task any thought before the lesson started, because it was necessary to inform them about the lesson’s activity. The second level of preparation can be described as that the students did decide on their own what physical model they wanted to depart from. For example, subgroup B1 and subgroup B3 had decided that they wanted to use the concept of Newton’s second law to determine the mass, but they did not think about how they should use the model in practice. The third level of preparation can be described as that the students knew what physical model or idea they wanted to depart from, and they also knew how they could use it in practice. For example, subgroup B2 wanted to create equilibrium between the object of interest and a second object with a known mass.
However, despite the different levels of preparatory work no group brought any resources or asked for any specific resources in advance.

**Weak knowledge of Terms and Concepts**

Subgroups that worked with Newton’s second law of motion showed clear evidence that they did not understand the general principle of the law, because in some subgroups the acceleration of the object was assumed to be the standard gravity due to falling objects. As a result, the students concluded that it was necessary to only measure the force that acted on the object. Furthermore, students had difficulty to explain the term *acceleration* in their own words and they mixed it up with the velocity of the object.

To use Newton’s second law of motion to calculate the mass of an object it was necessary to determine the net force, and the subgroups had problems to realize that it was critical to know the friction force to determine the net force, and therefore, subgroup B3 only determined the applied force on the object. It could be said that subgroup B3 translated the physics model wrong, which ended with a very unlikely result of the object’s mass.

Moreover, two students from different subgroups had a discussion about their results:

Student 1: How many Newton did you get?

Student 2: Well...

Student 1: Did you also get 340 Newton?

Student 2: We got 98.2 Newton...

Student 1: You know that 10 kilograms is 98 Newton. So, how much mass did you get? We were supposed to give the answer in mass, and not in kilograms.

This discussion indicated that one of the subgroups had lack of knowledge about the unit of mass, because he and his subgroup gave their answer of the mass in unit of Newton, which is the unit of the weight of the object.

**Relating Theory to Practical Measuring**

The students in subgroup B3 had problems to understand the term *acceleration* and to relate the theory they used to practical measuring. Furthermore, during the discussion between teacher and the students the term *velocity* was used regardless if the students talked about velocity or speed, and therefore, this terminology was also used in the presentation of the result.

*Task 2 Subgroup B3*

Teacher: What is acceleration?

Student 1: Increase or decrease of velocity.

Teacher: Yes, it is change of velocity, and if you know the change of velocity for the object then you also can determine the acceleration.

Student 2: And how do we know that?

Teacher: That is a question you need to answer. How can you determine the change of velocity?

[...]

Teacher: So, we know that the acceleration is constant, and if you know the initial and final velocity of the object then you can use this formula. The next step is to manipulate the formula so you can determine the acceleration.
Student 1: We should express the acceleration with this formula?

The students revealed difficulties to use algebraic operations on the formula

\[ v = v_0 + at \]

to express it in the following way:

\[ a = \frac{v - v_0}{t} \]

It was necessary to explain the procedure of algebraic operations in detail, and when the students knew the theoretical expression of the acceleration they needed to find out how they could determine by using practical measuring:

Teacher: Now you have an expression for the acceleration, but how can you determine it in practice?

Student 3: We need to find the velocity.

Teacher: How can you determine the velocity?

Student 1: Well... we can pull it a predetermined distance and measure the time, but we need to pull with constant velocity.

Teacher: If you pull the object with constant velocity will you then create a change of velocity?

Student 3: No...

[...] 

Teacher: You need to know the initial and final velocity and the time interval where the change of velocity occurs, and then you can determine the acceleration.

Student 3: Then we need tape measure and stop watch.

Teacher: What do you need the tape measure to?

Student 3: No, that is correct. We did not need that...

Teacher: How can you determine the velocities?

Student 1: We divide the distance with the time.

Teacher: That relation is only valid when we have constant velocity. What kind of device can measure the velocity?

Student 3: Speedometer...

Teacher: Can you use a GPS for cars?

Student 3: Yes, I think we can do that

In summary, it was necessary to understand how the theoretical description of the acceleration in form of formula could be used in practical experiment to gain a numerical value. Regardless the use of methods the subgroups had difficulties finding out how they could calculate the acceleration in the theory, and therefore, they also had difficulties to find a suitable method to measure the acceleration in their practical experiments.
Lack of Mathematical skills

The subgroups that used a formula to calculate the acceleration showed lack of mathematical skills because they had problems to perform algebraic operations on the formula. It was basic algebraic operations that needed to be used so the students could get the acceleration expressed in terms of time and velocities (this can also be seen in the previous category).

Furthermore, another evidence of lack of mathematical skills was revealed when students in subgroup B3 converted the units of velocity from \( km/h \) to \( m/s \). The students tried to remember a short-cut to do the conversion, but they showed insecurity about the method. As a result, they found the velocity of the object to be \( 21 \ m/s \ (\approx 75 \ km/h) \), which was very unlikely because they had only used muscular strength to move it.

Need of Step-by-step guidance

Guidance with the step-by-step method was used when the students did not have any specific ideas about how they should approach the problem. This method was used to help all students in Group A. The procedure of guidance was to ask leading questions in detail to the students, which made it possible for them to determine how they wanted to solve the problem. Moreover, the step-by-step method was used when the students wanted to use Newton’s second law of motion to solve the problem. As described earlier, students had problems with the general principle of the law and leading questions and instructions were necessary for the students to be able to design and perform their experimental setups. The students were not able to rewrite the formula so it expressed acceleration in terms of time, initial and final velocities by themselves, therefore it was necessary to show them the procedure in detail. Furthermore, it was necessary to ask questions to the students about different physical aspects as surface and friction force when they collected data, because otherwise the students would not had included those aspects in their studies. For example, the students needed to receive leading questions about the importance to determine the friction force when they used Newton’s laws of motion.

Some students did not need help with the step-by-step method because they only had problems with some parts of the problem solving process. In this case the students decided to use Newton’s second law of motion and with some leading questions and hints about how they could determine the forces the students were able to design and perform the experimental setup by themselves. Furthermore, subgroup B2 did not receive any help by the step-by-step methods, because they did not have any difficulties with the design and execution of their experimental setup.

Task 3: Study of pressure between solid objects

Instructional activity

The introduction of Task 3 was given to the class during a lesson and it took part in the classroom. The question, what provides largest pressure on the ground, you or a stone, was stated to the students, and then examples of different points of attack were shown. For example, cartoons in different positions were shown for the students to illustrate that the surface area was not predetermined. Furthermore, the students were also encouraged to make decision about the size and shape of the stones they should use. The students were instructed to find information about the concept of pressure and how it is determined, and suggestions of sources like the textbook or web-based pages were given.

The students could use an electrical scale to determine the mass of the stone, and a bathroom scale to determine the mass of their bodies.
The students worked in pairs in both groups, in Group A there were two subgroups and in Group B there were four subgroups. In total 12 students did participate in the problem solving of the task.

**Students’ activities**

The pressure between two solid objects can be determined with help of the formula

$$P = \frac{F}{A}$$

where $P$ is the pressure, $F$ is the normal force and $A$ is the area of surface area on contact.

Pressure is measured in force per unit area and the unit of the pressure is Pascal, $Pa$, which is expressed in Newton per square meter ($N/m^2$).

Three different methods to determine the surface were observed, and will now be presented to illustrate the different ways the students did approach the open-ended task.

In the first method the students identified the surface area as geometrical shapes, e.g. the surface area of the shoe was identified as a rectangle shape, and then the students applied a suitable formula to calculate the surface area of the shoe.

In the second method the students started to make a projection of the surface area on a piece of paper, and they then continued to identify geometrical shapes, e.g. the number of identical squares that fit inside the projection of the surface area. As a result, they could determine the area of each identical square with suitable formula, and therefore, they could also determine the total surface area.

In the third method it was possible for the students to calculate the surface area without identifying any geometrical shapes, because they used the concept of density. This method was introduced by the teacher, and therefore, the students received instructions and explanations how to use of the method. The students started to use a standard A4 letter, and determined the area and mass of it. Furthermore, the students did make a projection of the surface area on the paper, cut it out and determined the mass of the paper with the projection of the surface area. As a result, the students were able to determine the surface area by using the relation between mass and area. No consideration to the volume of the paper was necessary, because the same paper were used in the two calculations. This means that the volume was irrelevant to calculate, because the thickness of the paper was still the same and could be cancelled out in the calculations.

<table>
<thead>
<tr>
<th>Group</th>
<th>Side of stone</th>
<th>Surface area of human</th>
<th>Method of surface area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A1</td>
<td>Bottom</td>
<td>Both shoes</td>
<td>Method 1</td>
</tr>
<tr>
<td>Group A2</td>
<td>Bottom</td>
<td>Both shoes</td>
<td>Method 2</td>
</tr>
<tr>
<td>Group B1</td>
<td>Bottom</td>
<td>Both shoes</td>
<td>Method 2</td>
</tr>
<tr>
<td>Group B2</td>
<td>Bottom</td>
<td>Feet</td>
<td>Method 2</td>
</tr>
<tr>
<td>Group B3</td>
<td>Smallest area</td>
<td>One shoe</td>
<td>Method 1</td>
</tr>
<tr>
<td>Group B4</td>
<td>Bottom</td>
<td>Feet</td>
<td>Method 3</td>
</tr>
</tbody>
</table>

Table 6. Students’ choice of surface areas and methods
Table 6 presents the methods the subgroups used to determine the surface area during their work with the task. The table also presents which side of the stone the students chose to be the contact area with the ground and which part of their body they measured the contact area. Subgroup B3 used a brick in their experiment that they had used in previous task (Subgroup B2 in Task 2), and they chose the smallest area of the brick to be the contact area with the ground. Moreover, the rest of the subgroups used stones they found in the surroundings of the school zone, and the term bottom was defined as the side of the stone that was in contact with the ground when it was found in the surrounding.

Problems and issues identified while working with the task

The problems and issues that have been identified in students’ work with the task were separated into different categories, which will be presented now.

Absence of preparatory work

In a similar way as previous tasks, regardless of the introduction stressed that it was necessary for the students to be prepared for the task, no student had done any preparatory work. The preparatory work was expected to include search of information about pressure and how it could be determined. Furthermore, the students did not think about any resources that they might want to use because they did not have any knowledge about the concept of pressure. For example, all students knew they needed to determine the body weight of a group member, but no one did bring a suitable resource such as a bathroom scale or asked about it in advance. It was necessary to inform the students on which pages in the textbook they could find information about the concept of pressure. As a result, initiative from students to find necessary information by themselves did not occur.

The students followed the suggestion to find information about the concept of pressure in the textbook, and the information they found will be presented now.

You have probably experienced the difficulty to ski in fresh snow, and it will be easier to ski if your skis are wider. In that case your weight will be distributed over a larger area. The pressure on the snow will be less with wider skis. Apparently the pressure depends on the force and the area. For example, twice the force creates twice the pressure, and if the area increases to the double of its initial size then the new pressure will be half of the initial pressure. Furthermore, if we let \( P \) be the pressure then we can summarize these experiences in the formula

\[
P = \frac{F}{A}
\]

The unit is 1 N/m\(^2\) and is called 1 Pa (pascal) (Ekström & Boström, 2003:119-120, author’s translation).

It could be said that the information from the textbook gave an explanation how the pressure was affected due to the mass and surface area of the object. Furthermore, a suitable formula to calculate the pressure was given, and the textbook also showed an example of calculation of the pressure between solid objects.

Formulate solvable problems

Every subgroup had difficulties to formulate solvable problems, because they did not specify any problems they wanted to solve. It could be said that the students did make an opinion about which surface area of the stone and their body they wanted to use in their experimental setup, but they did not formulate a specific question which involved their definition of the
surface areas. As a result, without any guidance the subgroups chose the surface area that could be identified as the bottom area of the stone, which was the area that had contact with the ground in its natural environment. The surface area of the human part in the experiment was in general chosen to be shoes or feet. Furthermore, any comparison by changing the surface area of the stone or the body part was not done without guidance, which means that every subgroup in the first case only tested one specific scenario, regardless of the opportunities to test different scenarios. In summary, any formulated problem to the specific scenario could not be found, and the students expressed the surface area of the stone and their own body in general terms.

**Lack of Mathematical skills**

In general, all subgroups showed lack of mathematical skills because they had problems with unit conversion. First of all, the size of the stones made it suitable for the students to measure the surface area in \( \text{cm}^2 \), but to get the answer of the pressure in units of Pascal it was necessary to convert the measured unit into \( \text{m}^2 \). The conversion for length units were used by the students, and in this case between \( \text{cm} \) and \( \text{m} \), which has the relation that \( 100\text{cm} = 1\text{m} \). In the units of area the correct relation between \( \text{cm}^2 \) and \( \text{m}^2 \) is \( 10 \, 000\text{cm}^2 = 1\text{m}^2 \), and it was necessary to give guidance to every subgroup so they could perform the conversion correctly.

**Weak knowledge of Terms and Concepts**

The students had to determine the surface area of the stone and of their shoes or feet, and in general, the stones did not have surface areas that could be identified as regular geometrical shapes. Different methods to determine the surface areas were used by the subgroups and without guidance every subgroup determined the whole surface area of the stone and not only the part that had contact with the ground. This showed lack of understanding of the concept of pressure, because the surface area of interest was the area that had contact with the ground.

The students used the information they found in the textbook, and to demonstrate students’ lack of understanding of the concept of pressure an example will be shown.

![Figure 4: Contact surface areas of the stone](image)

a) Surface area determined by the students

b) Correct determined surface area
Figure 4 shows two different contact areas of the stone, which are the space inside the white-marked lines. Furthermore, Figure 4a shows the contact surface area the students usually determined, whereas the actual contact surface area of the stone can be seen in Figure 4b. On the basis of the rough surface area of the stone it was necessary to investigate the potential contact surface area carefully and then use an appropriate method.

The subgroups that used method 1 did not make any discussion about the sources of error for their method, which can be seen as a result that they did not reflect over the accuracy of the method. The teacher used method 3 to determine the surface area the subgroup A1 had determined by using method 1, and the teacher found that the area was 30% less than the surface area the subgroup A1 had determined. The comparison was only between different calculations of the same surface area and no consideration to the actual contact area was taken.

The subgroups that used method 2 to determine the surface area revealed different results and issues. First of all, subgroup B1 identified the surface area of the stone as a quarter of an ellipse, and they then used a suitable formula to find the surface area of the stone. However, they did not consider about the actual surface area of the stone, because they only considered the area that was defined as the bottom area of the stone. Furthermore, the two other subgroups that used the same method needed guidance to determine the surface area. For example, subgroup B2 wanted to approximate the surface area of the shoe as a rectangle. The students draw quadrangle with different length of the sides, and then they applied their measurements in the formula to calculate the area of a rectangle. As a result, the subgroup needed guidance to realize that their quadrangle could not be identified as a rectangle.

The students in subgroup B3 and B4 were able to determine the actual surface area, i.e. the area that was in contact with the ground. Subgroup B3 got rid of the contact area problem by using a brick, which had a flat surface area. In contrast to subgroup B3, it was necessary for the students in subgroup B4 to receive guidance and instruction from the teacher to perform the determination of the surface area with method 3. The reason to this procedure was that the students did not figure out the method by themselves.

**Difficulties to make feasible physics inferences**

Every subgroup made general inferences when they revealed their results, and their inferences were in the most cases inconclusive. For example, as described earlier students showed weak knowledge about terms and concepts, this also provided the students with inconclusive inferences in the sense that their inferences did not agree with the correct interpretation of the concept. It can be said that the students’ inferences were correct with respect to their result, but the execution of their experimental setups were based on an incorrect translation of the concept of pressure, which was illustrated in Figure 3.

The students did not refer to which scenario they performed the experiment, e.g. they referred to the surface area of the stone as it was the only possible surface area that could be found on the stone. Moreover, a general comprehension among the students was that the question they needed to answer only had one answer, and the students only performed experimental setup for one possible scenario.

In the following discussion between teacher and students in subgroup B1 the students used the term *hypothesis* both when they tried to explain their approach and their conclusions, which is the reason why the term also was used by the teacher during the discussion about their inferences.
Task 3 Subgroup B1

Teacher: What have you found out?

Student 1: Exactly my hypothesis, which was that the stone got 4 N/m² and pressure from Student 2 got 236 N/m².

Student 2: We must remember that this was when I stood up, and I did not lie down.

Teacher: What should you have gotten if you had lied down?

Student 2: Then it should have been very small... it would be pretty hard to measure...

Teacher: Does that situation change your hypothesis?

Student 1: Then it should be that there would not be any difference with the stone... it depends of the shape of the stone if this should be valid... A stone does usually never stand like this... a stone is always in general lying down if you see it in the nature and that is why this [hypothesis] is correct. If you measure when he [Student 2] is lying down then he will in principal be a very light stone, because his density has decreased.

Teacher: So his density has decreased?

Student 1: Well... it should have... or?

Teacher, So, our natural behavior is to stand up?

Student 1: No, it is to lie down. But we have already found that we won... or lose when we talked about mass per square meter if we should consider the surface area...

Teacher: Yes, when you consider this stone, but do that include every stone?

Student 1: No, it depends what it looks like, but a stone is in general... well... in proportional to the surface area... We have it like this; a stone has bigger distribution of mass than we have. If we take a guy with a mass of 80 kilogram and a stone with the mass of 80 kilogram, then the stone is always in principal more wide down there, i.e. the part that is in contact with the ground and the pressure will be lower.

Teacher: What is your hypothesis?

Student 1: Our hypothesis is that the pressure from the stone is lower than a human, because a stone will in general have a larger surface area. If a stone has the same mass as a human than the pressure from the stone will be lower [than the pressure from the human].

The discussion showed evidence that the students experienced difficulties to draw inferences from their result, and they tried to make general conclusion from their data. Furthermore, the students made inferences from scenarios they did not have any data. In addition, the language and use of non-relevant terms for the task made it difficult for the students to make their inferences understandable, and it also made it difficult for them to establish a connection between their results and inferences.

Need of Step-by-step guidance

The step-by-step guidance was needed when the students tried to understand the underlying theory they should depart from to be able to determine the pressure of different objects. Furthermore, the same type of guidance was necessary when they should determine the surface area of the different object in their experimental setups.
Three subgroups, where two of them were in Group A, needed step-by-step guidance during the whole problem solving session and the guidance was implemented by using leading questions and instructions about the problem solving process. It was necessary to explain concept of pressure for the students with help of verbal explanations and instructions.

All subgroups had difficulties in the unit conversion of the surface area, but the level of difficulty was not the same, which provided different types of help. For example, the students in subgroup A2 did use the ‘wrong’ side of the ruler and measured the sides of their rectangle in inches, but they thought their measurement was in centimeters. The students needed to be informed about which unit they have used in their measurement, and they also needed to receive detailed explanations and instructions how they could convert their unit for the surface area from \( \text{inch}^2 \) to \( m^2 \). Furthermore, the students decided to use their first measurement with the sides of the rectangle in the unit of inch, and did not see any simplifications to use the advice to measure the sides in the unit of meters from the beginning. On the other hand, the students in subgroup B3 also had problem with their unit conversion for the surface area. The students did measure the sides of the brick in centimeters and then they found the surface area in \( cm^2 \). The difference between the two subgroups was that this subgroup realized their mistake by themselves when they gave the answer of the pressure in unit of Pascal. Regardless that they found out their mistake by themselves, they also needed to receive hints about how the unit conversion between \( cm^2 \) and \( m^2 \) to perform it correctly.

The guidance was in typical a procedure where the teacher asked the students to explain how they had determined the surface area of the object, and if the students had converted the units in a wrong way the teacher asked leading questions so the students could find the proper way of conversion. In some cases the students admitted they did not know how to perform the conversion, and then the teacher explained how the conversion should be performed in detail. As a result, the students could be able to perform the correct conversion.

The same type of guidance was used when the students had problems to determine the surface area of irregular geometrical shapes. It was necessary to give guidance to the students who had chosen method 2 to determine the surface area. The questions were in the form of advice that it was possible to split up the surface area into several smaller areas, which could make it easier to determinate the surface area. Furthermore, subgroup A2 needed step-by-step guidance in the form of instructions and explanations how they should identify regular geometrical shapes in their projection of the surface area of the objects.

Some students did not need help with the step-by-step method because they only had problems with some parts of the problem solving process. The students were able to precede their work with help of general advice from the teacher. For example, the students in subgroup B3 did have some difficulty to find a point of attack of the problem.

**Task 3 Subgroup B3**

*Student 1:* What should we do... it [the pressure] will be different depending on which stone we use... it is not possible to... this is a question that there in reality does not exist any answer to...

*Teacher:* Then you need to specify a question you want to answer with your experiment.

*Student 1:* They will have the same [pressure] if their mass and area are the same.

*Teacher:* Yes, that is correct, but then you need to find a stone that have the same area and the same mass [as you] to be able to perform the experiment. You need to use a real stone, because you cannot just assume the mass and area of an imagined stone.
Student 2: Then we take the same stone we used before [in Task 2], that stone is flat so it will be more easily to calculate [the surface area].

As a result, with help of guidance in form of advice and leading questions the students were able to formulate a specific question, and could then precede their work without have received any step-by-step guidance.

Students’ experiences

The result from the interviews with the students will be presented in a similar way to the presentation of students’ activities, because every task was connected to a specific context. According to case study methodology this might highlight specific characteristics of the case. Furthermore, comparison between students’ experiences and their activity will be presented when possible conflicts have been detected.

Task 1

No one of the students did make any preparatory work regarding to formulating solvable questions or planning of necessary resources in advance. They came up with ideas during the lesson, and the reason was that they usually did not make any preparations before physics lessons.

Furthermore, one of the students had difficulties to retail his hypothesis, which the example below will illustrate:

Student: I do not remember it so well, but I think it was the acceleration...

Teacher: You investigated if the surface area of the object affected its fall.

Student: Yes, and we found out that it did affect the fall.

The student also claimed that the task was easy to perform, and he did not reflect over possible sources of error during his performance of the task. However, the result from students’ activities showed information that the student needed help in the form of instructions and hints to be able to formulate and design his experimental setup.

Moreover, the other student did not think that the formulation of a problem was difficult to perform, but he said that it was difficult to design the experimental setup because he did not know in advance what resources that was available in the school building. In comparison with the result from the students’ activities this student was not the only one who did not know what available resources they could use.

Task 2

This task did not require any formulation of a solvable problem, but it required ideas from the students about how they could approach the task. The result from the discussions with the students revealed the same answer as in the first task, which was that the student did not make any distinct preparations about how they could approach the problem.

However, the result revealed the information that the students did have different ideas about how they could approach the problem. For example, one of the students had an idea to construct a large balance scale, but he did not bring any necessary resources to the lesson. The student did not know how he came up with the idea, but he think it was because it was a primitive method that he thought he had seen or experienced earlier. According to the student, he did not experience any difficulties when he designed his experimental setup, but likewise the first task he thought that he could have performed the experiment better if he had access to more suitable materials to build the large balance scale.
The reason why the students did not make any preparations in advance was the same as in the previous task. Furthermore, the same student did again claim that the task was easy to perform, and his argument was that it was like doing math problems. However, he did again have problems to explain his experimental design because he was not sure if he had used a physics model or not.

**Task 3**

As described in the result of the students’ activities with regard to their preparations the result showed that the students did not make any preparations, however, one of the students argued that he made some preparatory work because he decided beforehand from which side of the school building he should look after a suitable stone. Furthermore, the students did not make any preparations with respect to the formulation of a solvable problem, and they gave the same reason as in previous tasks; they do not usually make any preparatory work before a physics lesson.

Furthermore, both students said that they did not experience any difficulties when they designed and executed their experimental setups. However, the result from the students’ activities in this task showed that every subgroup did have problems to perform the correct unit conversion. When the teacher asked the students about this difficulty one of the students admitted that his conversion was performed wrong, and he found out the physical unlikeness of the result and realized that something was not done correctly. However, the other student did not agree that he had experienced any difficulties with the task.
Discussion

The results of the study will be discussed in relation to the research questions, and also to the study’s validity and suggestions to further research. Hence, the discussion involves the following topics:

- Value or influence of students’ previous experience and knowledge
- Discussion of students’ difficulties in their approaches to the different steps of the problem solving process
- Level of guidance
- The study’s validity
- Conclusions and Further Research

Value or influence of students’ previous experience and knowledge

I this section I will discuss the results that are related to the following research question.

- How often does teacher’s activity include work with open questions and open-ended problems?

Furthermore, this section will also include discussions about how the result of the research question can be attributed to students’ behavior in their work with the tasks. The discussion will be presented in two categories, lessons and laboratory work, because in a report based on study of literature, laboratory work are described as isolated exercises in the sense that they have little or no relationship to earlier or future work (Hult, 2000).

Lessons

First of all, the structure of the physics lessons matched with my own experiences from physics lessons in upper secondary school, and the result showed that the teacher preferred to use well-performed demonstrations to introduce or explain terms and concepts. In similar way, Ekstig (1990) pointed out that demonstrations in the classroom are one of the most important elements in the teacher’s working method, because the demonstrations have possibilities to create interest and curiosity among students. However, the demonstrations often included verification of theories or concepts, and therefore it can be possible that only one answer or explanation can be found. Moreover, the results showed that students had the opportunity to calculate end-of-chapter problems in the end of the lessons, which matched with my own experiences. Summing up, the structure of the physics lessons did not reveal any clear indication that the teacher’s work included distinct open-ended problems.

The results of the teacher’s activity during the lessons revealed that closed questions were frequently used. Physics is presented as an open and dynamic science, and therefore the result was an interesting finding because the teacher’s activity could be seen as the contradiction to the general presentation of physics. An explanation to this behavior could be that the teacher wanted to get insight about students’ knowledge in the form of facts and understanding, because the Swedish Agency of Education (Skolverket, 2006) categorized them as different kind of knowledge. However, research showed that teachers’ behavior can influence students’ perception about the interest and relevance of the subject (Gorham & Christophel, 1992), and therefore, teacher’s activity with closed questions can be attributed to students’ perception that a physics problem only had one correct answer or explanation. Finally, it can be said that this study did reveal that the teacher preferred to use closed questions during the physics lessons.

The results suggested that the students preferred to come up with one specific result when they worked with open-ended problems, regardless of the opportunities and encouragement to
test different scenarios. It could be said that the students for some reason had the idea that only one possible answer of every problem was possible. Therefore, it is necessary to discuss the result of the research question in relation to how it can be attributed to the students’ behavior, because socio-cultural theories described that students’ previous knowledge can contribute to their present learning (Vygosky, 1974).

The structure of the physics lessons and the type of questions asked by the teacher can be attributed to students’ behavior to only test one specific scenario. Furthermore, research has shown that students’ goal of the problem solving was to find a numerical value, and when that goal was achieved the students usually did not evaluate their result (Heller et al, 1990). It could be said that these activities can be attributed to students’ perception that physics problems only had one correct answer or explanation.

Laboratory work

The result showed that the laboratory work the students performed during the physics course used traditional instruction, and step-by-step instructions were usually given to the students. The teacher considered that the students performed the experiments better with step-by-step instructions in comparison with less detailed instructions. The laboratory work can be seen as a central part when studying physics (Ekstig, 1990; Skolinspektionen, 2010). Furthermore, the most frequent used form of laboratory work was to verify theories or constants, and the experiments were well-structured and included step-by-step instructions. The purpose of the structure was that the students should get a perception about the result they were expected to find and the work they needed to perform. The reason to this procedure of laboratory work was that many students had problems to work with less detailed instructions and they needed to know what they were expected to find in the performance of the experiments (Ekstig, 1990). It can be said that the results clearly indicated that the teacher did not use open-ended problems in the laboratory work, and the explanations could be related to factors that is out of scope of this study, such as teacher’s time to plan laboratory work and his purpose and experience with laboratory work.

However, students do not necessary understand the process and techniques in the laboratory work, despite that traditional instructions with step-by-step method were used. In addition, the most laboratory works verify something that the students already knew, and the lack of post-work can make it difficult for the student to connect the theory with his experience from the experiment (Hult, 2000). Therefore it could be said that laboratory work with step-by-step instructions can be attributed to students’ perception that physics problems have only one correct answer or explanation, and the laboratory instructions do not necessarily help the students to become more used to performing experiments.

Students’ difficulties in their approaches to the different steps of the problem solving process

In this section I will discuss students’ problem solving activities following ‘six steps model’ of problem solving introduced in the theory chapter, and the aim is to answer the following research questions.

- How do technical program students prepare to work with open-ended problems?
- What difficulties do students reveal in the different steps in the problem solving process?

To be able to answer the first research question the term preparation needs to be more carefully defined with inspiration from the results.
Cognitive preparation – students needed to make preparations in the form of formulation of questions and methods of solution.

Practical preparation – students needed to make preparations in the form of arranging access to suitable materials and resources for their performance of practical experiments.

The students’ performance of these two types of preparation will be discussed in relation to their difficulties that were revealed in the different steps of the problem solving process.

Step 0: Identify and formulate ‘solvable’ problem

The result suggested that the students had different levels of difficulty to identify and formulate solvable problems in their work with open-ended problems. This means that the students did not have the same problem in their performance of this step, but they all have some level of difficulty to know how to approach the problems when data, method and goals were not given explicitly to them. The results showed that the students in Group A did have more difficulties to identify and formulate solvable problems in comparison with students in Group B.

Furthermore, the result showed that the tasks provided different difficulties for the students to perform this step. In the first task the students had difficulties to decide which parameters they wanted to investigate. The reason for this could be that the question did not provide any information about specific methods or objects to use in their experimental setups. In the third task the object of interest was already determined and the students had problems to explain which scenarios they wanted to investigate, and it can be said that they made a definition of a scenario they thought was the correct one, which has been described as the ‘natural’ state of the object.

It was not a surprising finding that the students had difficulties to make cognitive preparation to be able to formulate solvable problems, because they were used to work with closed end-of-chapter problems with given answers. However, it was an interesting finding in the sense that the students did have preconceptions and ideas about the tasks, but they did not perform any preparatory work at home to be able to identify and formulate solvable problems.

Previous research has shown that students can have difficulties to work with open-ended problems because they are unfamiliar to this type of problems (Elmqvist & Jönsson, 2002). Students are used to get well-structured and closed problems, which can be attributed to their difficulties to be creative and to perform independent work (Skolverket, 1996). Therefore, it was interesting to find that the students did not make any cognitive or practical preparations in advance, even though they were encouraged to make suitable preparations.

The role of the students can be seen as passive when they performed this step, because they did not make any preparatory work, and the result also showed that the students needed some sort of guidance to be able to perform this step. Educational evaluators has described that the procedure of the physics lessons do not contribute to students activity because transmission pedagogy is used, therefore, it was interesting to find that students did not take responsibility for their learning when the tasks required them to be active and to make decisions about their approaches of the tasks. It is possible that this behavior can be attributed to students’ previous experiences and knowledge.

Step 1: Visualize the problem

The results showed that the students did not visualize the problems, and this finding was important because it can be described as the students did not create a visual presentation of the problem, and therefore, they had difficulties to understand the problem. This was an
interesting finding, because the tasks included phenomenon that the students could experience hands-on in their everyday life, which created opportunities for the students to use their knowledge to be able to understand the problem. Furthermore, they should depart from known physics models and concepts to be able to visualize the problem before they could move forward to the next step in the problem solving process. However, the result did not verify that the students performed this step as a separate part in their problem solving process.

It can be said that this step was related to the previous step in the problem solving process, and as described earlier the students did have different levels of difficulty to perform the previous step. Hence, students’ difficulties and absence of performance of this step was not surprising, however, it was interesting that the students avoided this step and tried to plan their solutions directly from the formulation of the problem. The students did approach the problem in the same pattern as described by Heller et al (1990) when they had formulated the problem. Furthermore, some of the students can have performed this step coincidental with the next steps in the problem solving process, and this aspect will be discussed later, but it can clearly be stated that the students did not perform this step separately without guidance in their problem solving process.

Students’ difficulty to create a visual presentation of the problem can be attributed to their lack of sufficient knowledge, and therefore, they could also have problems to find a suitable approach to describe the problem in form of visual presentation. As described in the previous step, students’ experiences of traditional physics teaching can also be attributed to the absence of performance in this step. For example, my experience from upper secondary school revealed the information that it was not always necessary to use visual presentation to solve the end-of-chapter problems, and it was not either necessary to visualize the problem in the performance of laboratory work with detailed instructions.

**Step 2: Describe the problem in physics terms**

The findings revealed the information that the students did have weak knowledge of concepts and terms, and therefore, they also had difficulties to describe the problems in correct physics terms. Furthermore, physics models are based on concepts and terms, and therefore, this finding was important because it showed that the students had problems to understand the physics models and concepts they used when they approached the tasks.

Previous research has showed that students can have difficulties to understand the representation of formulas (Reid & Yang, 2002B), and misconceptions can appear because the students construct their own ideas based on their previous experiences (Wessel, 1998). This study has departed from the theoretical framework that describes the role of previous knowledge, and therefore, this finding can be seen as expected. Furthermore, the description of the problem in physics terms required accurate knowledge about the relevant terms regardless if the knowledge had been constructed outside or inside the classroom. In students’ work with the tasks the responsibility of learning has been transferred from the teacher to the students, and hence, it can be argued that the students also had the responsibility to check that they described the physics terms accurately. The results showed that the teacher needed to help the students to be able to explain the correct interpretation of the physics terms if the students had another interpretation about them. It was an interesting finding that the students had difficulties to explain frequently used physics terms as velocity and acceleration in their own words and how these terms can be interpreted in practical experiments.

Students’ approaches in this step revealed the finding that if the students had difficulties in the previous steps then they also had difficulties in this step. This can be explained by the fact that if the students were not able to identify the problem or to create a visual presentation of it, then it was not a surprise finding that they also would have problems to describe the
formulated problem in physics terms. In other words, the students were not used to construct physics models and to see the connection between physical phenomena described by formulas and their own experience of reality. This scenario has already been shown by previous research, for example see Popov & Eng (2007).

**Step 3: Plan the solution**

This step in students’ problem solving process revealed several findings concerning students’ creativity in their planning, and also their difficulties in the same process. Furthermore, the findings revealed that the students’ skill was a contributing factor to their approaches in this step.

First of all, the results showed that the students did not make any practical preparation with consideration to use suitable materials and resources, and therefore, the students were forced to use materials and resources they could find in the surrounding of the school building. This revealed interesting finding about students’ creativity and their abilities to use it in their planning of the solution. For example, one subgroup used material they could find in the surroundings to build a large-sized balance scale.

However, not every student showed this example of creativity in their planning step, and the findings revealed different kind of information regard to students’ approaches to plan their solution. The first finding concerned students that knew theoretically how they should plan their solution, but they had problem to relate their theories to practical measuring. This finding was evident, because previous research has found that students can have problems to relate physics models to the reality (Popov & Engh, 2007). One reason to students’ difficulties in this step can be related to that they can have performed step 1, 2 and 3 in the problem solving process coincidentally, and therefore, they tried to plan a solution without clearly distinction of what concepts and terms they have departed from. In this approach of the step the students tried to plan their solution directly from the problem formulation, which can be argued to be difficult if the students have lack of understanding of the essential concepts and terms.

Furthermore, the findings also showed that some students did not have any ideas how they should plan their solution, and it is possible to conclude that this problem can be attributed to the students’ difficulties in previous steps. In similar way, this finding was not a surprise because previous research has shown that this step can be the most difficult in students’ problem solving process (for example see Byun et al, 2008). The findings also showed that the students had difficulties to see the connection between the theory and the practical measuring, which can be attributed to the students’ difficulties to plan their solutions.

The tasks have been designed in such way so the students had the possibility to perform multiple solution methods, and hence, it was interesting to find that the students showed low interest and creativity to plan different solutions methods and scenarios. As the results showed, every subgroup constructed one solution method to each task, regardless of the opportunity to use multiple solution methods and approaches to the problem. It can be argued that this behavior can be attributed to students’ previous experience in problem solving and laboratory work, because in those situations mostly one solution method were used. It was interesting that the students did not show more interest and creativity to approach this step with several ideas and solutions methods, even though they had been informed that no restrictions to solutions methods were bound by the problems. Furthermore, the students’ unfamiliarity to work with open-ended problems can be attributed to this behavior, and their familiar manner to use one solution method in their work with problems might have more influence than the information that multiple solution methods and scenarios were possible.
Step 4: Execute the plan

The students experienced different types of difficulties when they executed their plans, and these difficulties can be related to lack of mathematical skills and to problems with practical measuring. It can be said that students’ approaches in this step revealed both interesting and unexpected findings, and the discussion will start with the unexpected part of the findings.

The unexpected finding in the students’ approaches in this step was that the students showed lack of mathematical skills. This was remarkable because the mathematical operations were familiar to the students. In other words, the students should have received sufficient mathematical knowledge to be able to perform the mathematical operations routinely when they knew the goal of a specific mathematical problem. Furthermore, students’ difficulties to perform familiar mathematical operations cannot be related to another interpretation about the physics terms, because the operations did not require understanding of the physics terms that were involved in the formula. For example, the mathematical operations to make the following manipulation

\[ v = v_0 + at \rightarrow a = \frac{v - v_0}{t} \]

does not require understanding of the physical representations for the symbols in the formulas, but still the students had problems to perform the essential mathematical operations.

The difficulty of the task could be an explanation to why the students experienced problems in this step, but in comparison with the end-of-chapter problems that could be found in the textbook, the same mathematical operations was necessary to use to solve those problems. Hence, it is possible to determine that the mathematical difficulty of the task was not the source to students’ lack of skills to perform the mathematical operations, and therefore, their knowledge in mathematics can be attributed to their difficulties in this step. However, this aspect is out of scope for this study, because the tasks were designed in relation to the knowledge the student should perceive in physics.

The second finding concerned students’ difficulties related to practical measuring, and the results showed that students had difficulty to understand the physical interpretation of formulas and relate them to practical measurement. This finding was expected, because previous research has showed that students are not used to construct their own physics models, and they have problems to understand the connection between phenomena described by formulas and the reality (Popov & Engh, 2007). This finding was important because it revealed students’ inexperience to perform experiments with open-ended problems where independent variables were not predetermined. It can be argued that the students’ education should prepare them for the ‘real world’, thus an environment where specific problems or questions may not be clearly stated and described. Therefore, the students need to be able to make decisions about variables. Hence, students’ treatment of independent variables was an interesting finding, because their work showed evidence of insecurity in their decision-making about the importance of independent variables to be able to get consequent and accurate data, and to perform systematic measurements. Possible explanation to this behavior can be students’ inexperience to work with problems that require decision-making and careful treatment of variables, because traditional experiments do not create opportunities for those selections.
Step 5: Check and evaluate

The result suggested that the students had problems to draw inferences and evaluate the reasonableness of their results, and different level of difficulties to draw inferences have been found among the students. This means that the students did not have the same problem to draw inferences, and the difficulties can be separated in three different categorizes.

The first category is that the students were not able to draw any inferences at all from their results, and they needed to receive hints, instructions and explanations to be able to evaluate their results. It was not a surprise in the case where the students had difficulties in the previous steps of the problem solving process. Furthermore, the majority of the subgroups in Group A revealed this kind of difficulty. It can be said that if the students had problems to identify, formulate, and describe the problem and then also to plan and perform practical measurement it is natural to conclude that this step would also be difficult for them.

The second category is that the students were able to draw inferences about their results, but their inferences can be described as inconclusive. The reason to this categorization is that the arguments were not always based on results from their experimental setups. This showed that the students had difficulties to focus their inferences within tight frames of their experimental setup, and they generalized their findings without reflection over the validity of their experimental setup. Furthermore, the majority of the subgroups in Group B revealed this information, in comparison with Group A where most subgroups had problems to make any inferences at all. It can be argued that the students in this categorization showed knowledge when they made generalization. However, the students approached this step with generalizations without reflection, which can be a source for prospective misconceptions. This was an interesting finding, because even though open-ended problems created opportunities to draw different inferences from the results, the inferences still needed to be drawn from the results and the experimental setups, and generalizations were maybe not always possible to conclude.

The third category is that the students made inferences based on wrong translation of physics concepts. This was an important finding, because it can be argued that the presentation of physics as an open science could encourage the students to critically examine their translation of the physics problem into mathematical representation when they evaluate their results. However, the results suggested that this behavior did not occur, because students made inferences based on wrong translation of physics concepts. For example, students’ inferences about the comparison of pressure between two different objects were based on the wrong translation of the physics concept. The students were able to make inferences about their result despite their wrong translation, but the interesting part was that the students did not reflect over this possibility when they revealed their inferences. Furthermore, no distinction can be seen between the two groups, because all subgroups had problems to make a correct translation of physics concept in this case.

Regardless of the different difficulties the students experienced in this step it can be said that the students needed guidance to approach this step in the first place. In other words, students’ problem solving process ended after the previous step was performed because they had received a result in form of a numerical value. The students needed to be informed that they should evaluate their results and experimental setups, which previous research has shown that students rarely perform, for example see Heller et al (1990). It can be said that students’ goal with the problem solving process in their work with open-ended problems was to receive a result, and students’ previous experiences of traditional physics teaching can be attributed to this behavior. Therefore, students’ lacks of abilities to make inferences are not unexpected,
but their disinterest was surprising because in their future work they might need to be able to evaluate their results and findings.

**Level of guidance**

In this section I will discuss the results that are related to the following research question.

- **Which levels of guidance do the students require in their work with open-ended problems?**

The result suggested that two different types of method for guidance were used during the students’ work with the open-ended problems, where the step-by-step guidance could be identified as one model of guidance. The second type of guidance requires a definition based on the findings and corresponding research, but first the method of step-by-step guidance will be described in more detail.

As described above, the result of the study showed that guidance expressed as step-by-step guidance were performed, and this type of guidance can be described as a method to explain for the students in detail how they can solve the problem. The method used leading questions, explanations and demonstrations about the correct procedure of solution method. For example, this type of guidance was used when the students had difficulties with mathematical skills or when they did not understand the underlying theory in physics models, and therefore, they were not able to solve the problem without detailed instructions and explanations.

As mentioned earlier, the step-by-step guidance was not the only type of guidance that assisted the students to solve the problems. The other type of guidance the students received was in the form of new questions and hints they could to take into consideration to be able to solve the problem. Furthermore, the method did not explain for the students how they could solve the problem in detail, because the purpose with the procedure was to help the students to move forward in their problem solving process. This type of guidance can be defined as a *Next level guidance*, and the purpose with this type of guidance was to help the students to move forward in the problem solving process without explaining the solving process in detail. This process can be seen as the *zone of proximal development*, which is the difference between what the students can do without help and what they can do with help (Vygotsky, 1978). It could be said that the students were able to perform the problem solving process after they received help in the form of leading questions and hints. This assistance helped them to move forward in their work, and therefore, the difference between what the students could do with and without help were identified, and thus the process can be seen as the zone of proximal development. Furthermore, an example of intervention of assessing the zone of proximal development:

*We assist each child through demonstrations, leading questions, and by introducing elements of the task’s solution* (Vygotsky, 1934/1987:209).

The definition of the *Next level guidance* implied that cooperation was necessary when the students had difficulties in the problems solving process, and two features of effective cooperation have been identified by laboratory studies and naturalistic observations. Wood & Wood (1996) describe that the first feature is when the students’ existing knowledge and skills are not sufficient to solve the tasks. The teacher can help the student to gain sufficient knowledge that was demanded for the task. The second feature is that the teacher can provide a structure to support the student’s problems solving process, and this can be done by providing instructions and help in the context of the student’s activity. As a result, the student has an active role in the learning even though the problem was defined as an ‘out-of-reach’ problem from the beginning. Consequently, the responsibility has been transferred from the
teacher to the student and the procedure can contribute to the successful solutions of problems.

Wood & Wood (1996) also suggest that effective helping is two-parted:

- The first part is when the student gets into difficulty, and when this happen the teacher can provide more specific instructions or help than was offered previously.
- The second part is to provide minimal help to the student so he can ensure joint success. For example, this can be done by replace visual demonstrations with verbal explanations and hints.

The Next level guidance in the problem solving process can be seen as an implementation of Vygotsky’s theory about the zone of proximal development, but the result of the study revealed that this kind of guidance was not applicable to use in every case when it was necessary to help the students. Students’ previous knowledge and experiences contributed to which level of guidance that was necessary to give the students, and the result also suggested that students’ interest and creativity can be attributed to which level of guidance that was necessary to offer the students.

Furthermore, the result showed that the level of guidance between the two groups was in general different. It can be said that students with higher mathematical skills received less help in the form of step-by-step guidance in comparison with the students with lower mathematical skills. The students in each group were at the same mathematical level, and this could be a reason to why one of the groups needed to receive more step-by-step guidance than the other group. It could be possible that the students with the lower mathematical skills were not able to help each other because of lack of sufficient knowledge. Another explanation to the difference between the groups with the consideration to the different level of guidance could be lack of cooperation. This aspect and the possible influence of the group constellations will be discussed further in the case of the validity of this study.

Summing up, two different types of guidance can be used to help the students in their work with open-ended problems. This makes it possible to adapt the type of necessary method of guidance individually to each student with respect to their knowledge in the physics topic. For example, it is possible to give detailed and structured help to students who require it. Furthermore, it is possible to accommodate the level of guidance in form a less detailed and structured help to students who do not require step-by-step instructions. Hence, students different needs, precondition, experience and thinking can be taken as starting point in the physics course, and this process can also create opportunities for the students to be active and to take responsibility for their learning, which hopefully will increase the students’ motivation, interest and knowledge about physics.

The study’s validity

The validity of this study will be discussed in relation to the choice of problem solving strategy, the use of research method and possible affects from context-based circumstances.

Problem solving strategy

The problem solving strategy was inspired by Heller’s development of a problem solving strategy for context-rich problems, and it can be argued that this problem solving strategy (and also the problem solving model developed by Byun) was originated from an overall framework for problem solving described by George Polya. Although the framework’s focus was on solving problems in mathematics, the strategies can be seen as general and could be broadly applicable. The framework included four steps that were necessary to take into consideration in the problem solving process:
The first step was to understand the problem, which required that the solver read the problem and make sure that he understands it.

The second step was to devise a plan, which included finding a connection between the given information and the unknown so the solver was empowered to obtain the idea of solution.

The third step was to carry out the plan that was devised in the previous step.

The fourth and last step was to look back and be critical to the received result, which included evaluation and discussion about the result and the process of the problem solving to discover any inconsistencies or incorrect steps (Polya, 1990).

It can be argued that the steps in the two different solving problems methods developed by Heller and Byun were modified after the framework to be adapted to physics problems. Furthermore, Heller’s problem solving method was chosen in this study on the basis that it was developed in relation to context-rich problems, which can be described as real world problems. Consequently, the relation between context-rich problems and authentic problems developed in the outdoor physics approach can clearly be stated, and hence, it was suitable to use the problem solving method in this study.

Research methods

This study combined three methods of data collection, which contributed to the possibility to triangulation. Furthermore, Johansson & Svedner (2006) declared that the combination of qualitative interviews and observations are the primary research methods in the performance of an educational related study. Possible difficulties about the different methods of data collection will be discussed now.

First of all, the teacher was unknown of the occurrence and purpose of the observations of his activities, and hence the result should reflect the standard procedure of the lessons. Furthermore, the result could be affected and not revealed the situation properly if the teacher knew about the occurrence of the observations.

Data collection of students’ activities was performed during scheduled physics lessons, because it was necessary to perform the study in the students’ natural context. The students were not informed about the purpose of the study, because otherwise they could have affected how they approached open-ended problems if they knew the focus of the study. Hence, the result could have been different and not represented the problems that have been identified.

The number of participants in the interviews with students was not optimal, because it generated difficulty to make any general conclusions from the gained information. The study did not reveal information about all students’ opinions, and it could be possible to find other opinions among the rest of the study group. Therefore, general conclusions about students’ individual work with the tasks are difficult to make, because the study was performed in a specific context. On the other hand, it can be possible to make conclusions about general difficulties in the problem solving process and level of guidance that were also supported by other findings.

The interview as a research method can both have advantages and disadvantages, and possible difficulties and related problems to this method will be discussed now.

First of all, the students in the interviews could be affected by body language and face expression and especially in a situation where the interviewer could have influence on the respondents’ answers (Johansson & Svedner, 2006). In the interviews with the students this type of issues was necessary to take into consideration, because there was a situation of power between the respondent and the interviewer in the form of a ‘student-teacher relation’. This situation could influence the respondent’s answer. To minimize the effect of this possible
situation of power the respondents were informed about the voluntariness of the participation in the interview, and that the interview should be seen as a discussion about the respondents’ opinion about the tasks. Furthermore, the respondents were informed about the topics in advance and the interviews were performed at places and times suggested by the respondents. This procedure was performed to minimize the possibility of respondents’ answers being affected by the relation between the respondents and the interviewer.

Secondly, the respondent in the interview could express opinions that he thought the interviewer wanted to receive regardless if the opinions agreed with the respondent’s actual opinions (Johansson & Svedner, 2006). The respondents were not informed with the actual purpose of the interview, and this choice was made to minimize the affect described above. However, every respondent was informed that his genuine opinion could contribute to a better understanding about his work with the problems, and he were also informed that he had the right to decline to answer questions he did not want to discuss.

All data collection from students’ and teacher’s activities needed to be translated from Swedish into English, and therefore, it is possible that information can have been lost in the translation. Furthermore, information can also have been lost in translation when I have used Swedish articles and other resources written in Swedish.

**Context-based circumstances**

This study was performed in a specific context, where the teacher made decisions about the group constellation and if the students’ work with the tasks should be graded or not. The study needed to be adapted to those decisions, which might have influence on the result.

In the discussion earlier about the difference between the two groups with respect to the level of guidance two aspects were brought up that concern the validity of the study. The first aspect was the group constellation, and it is possible the result might have been different if the group constellation had been different. For example, the groups could have included students with both high and low mathematical skills. The second aspect was that students’ necessity to receive step-by-step guidance could be because of lack of cooperation, but on the other hand, the students had the opportunity to choose the members of their own group and it can be seen as their responsibility if they used this opportunity or not.

The problems the students experienced in their work with the open-ended problems can be attributed by the fact that their work were not graded, and therefore, it can be possible that the students did not have motivation or interest to solve the open-ended problems carefully. On the other hand, the students still possessed the same knowledge regardless if the tasks were graded or not, and hence it is possible to make the conclusion that the student’s problem should have been revealed irrespective of the occurrence of grades or not.
Conclusions and Further Research

From the discussions about students’ approaches to the different steps in the problem solving process it can be concluded that students’ difficulties in the different steps can be attributed to inexperience to perform laboratory work that includes open-ended problems, and weak knowledge of physics models and concepts. Therefore, if the students work with open-ended problems regularly they can achieve better knowledge of scientific inquiry and be more used to perform practical work in scientific rather than algorithmic way.

Furthermore, it can be concluded that different level of guidance were possible in the work with open-ended problems, which created opportunities for the students to take responsibility for their learning, and the level of difficulty in the problems could be adjusted to the students’ individual knowledge.

Moreover, it would be interesting to implement the outdoor physics approach in the physics course to study the effects of it when it is a part of the course and not only an additional element. The implementation of the outdoor physics approach can be seen as supported by the new syllabus in the physics course, because it stresses that students need to formulate questions. Therefore, studies with the open-ended problems implemented in the physics course need to be performed to be able to investigate the effects of the approach.
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Appendix

Interview descriptions

The interview with the teacher and the students were designed to be qualitative interviews, which mean the topics of the interview were established and possible attendant questions were created depending on the answers from the different respondents.

Teacher

*Planning the lessons*

- How did you plan your lessons in the physics course?
  - Introduction to topics?
  - Demonstrations?
  - Experiments?
  - Calculation performed by the students?

*Contribution to scientific ways of thinking and working*

Quotation from the curriculum of the non-compulsory school system (Skolverket, 2006:5):

*Pupils shall train themselves to think critically, to examine facts and their relationships and to see to the consequences of different alternatives. In such ways students will come closer to scientific ways of thinking and working*

- What is your opinion about the possibility of the physics lessons to contribute to this goal?
- Do the physics lessons already contribute to this goal?

*Laboratory work*

- How does the structure of the laboratory work proceed?
- What types of information are given to the students?
- In which ways are the information given to the students?
- How do the students perform the experiments?
- What are your expectations that the students should learn from performing the experiments?
- What is your comprehension about the activity and creativity among the students?

*Guidance during problem solving*

- How does the usual procedure to he lp students occur?
- Can it be possible to use different methods to help the students depending on each student’s knowledge?
- What is important to be focused on when the students need help?

Student

The same topics were the same, but the possible attendant questions could be different depending on which task that was brought up to discussion.

*Task 1*

- Can you describe how you did approach the problem?
  - How did you find out that idea?
- Did you experience any difficulties when you worked with the task?
  - Preparatory work?
  - Formulate solvable problem?
- Source of error?
- Constant parameters?
- Make conclusions?

Task 2

- Can you describe how you did approach the problem?
  - How did you find out that idea?
- Did you experience any difficulties when you worked with the task?
  - Preparatory work?
  - Concepts and terms?
  - Relate theory to practical measuring?
  - Mathematical difficulties?

Task 3

- Can you describe how you did approach the problem?
  - How did you find out that idea?
- Did you experience any difficulties when you worked with the task?
  - Preparatory work?
  - Formulate solvable problem?
  - Concepts and terms?
  - Relate theory to practical measuring?
  - Mathematical difficulties?

General opinion about the tasks

- What is your opinion about solving a problem where the result or solution method is not described clearly?
- What is your opinion about a problem that requires the solver to move out from the classroom to be able to solve the problem?