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The Problem-Solving Process in Physics as Observed when Engineering Students at University Level Work in Groups

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Abstract

The problem-solving process is investigated for five groups of students when solving context-rich problems in an introductory physics course included in an engineering program. Through transcripts of their conversation the paths in the problem-solving process have been traced and related to a general problem-solving model. All groups exhibit backward moves to earlier stages in the problem-solving process. These earlier stages are revisited by the groups for identifying sub-problems, setting parameter values or even restating the goal. We interpret this action as coming from the fact that the students have not yet developed a knowledge base and a problem-solving scheme. Connected to the backward moves in the process are opportunities for the group members to build such a knowledge base from contributions and experiences from all group members. Problem contents that induce such moves are identified and can thus be considered by science teachers when constructing problems for group work.

Keywords: problem solving; physics; physics education; context-rich problems; collaborative learning; group work

1. Introduction

Due to the declining interest among young people in the Western world, especially Europe and Japan, for careers in the area of mathematics, science and engineering (OECD 2006; Osborne and Dillon 2008; Sjøberg and Schreiner 2010) our welfare system is challenged. To match the demands from the industry and public sector regarding engineers and other professionals trained in technology, presumptive students for engineering studies must be looked for more broadly and in new groups. Students in the engineering program investigated in this study have diverse study backgrounds. We have enhanced the instructional approach by introducing the possibility for students to

talk physics and we have in connection with this science conversation with peers experienced how the students develop knowledge of concepts (Enghag et al. 2007, 2009; Jonsson et al. 2008). The observations and reflections from these physics courses are the ground for this case study on physics problem solving in groups.

Collaborative learning in small groups has been a pedagogical tool in physics education for a long time in order to give opportunities for the students to express themselves with newly accessed knowledge in a relevant context. A meaning-making of concepts, their relations and also limitations of models used is facilitated if you are allowed to discuss them in a social context (Driver 1994; Leach and Scott 2003; Redish 1994). The importance of language in learning has been shown (Bakhtin 1986; Barnes and Todd 1995) and it has even been argued, that talking is better than writing for learning science (Roth 2005). Research also shows (Prince 2004) that active learning, including collaborative learning, leads to improved results for several learning outcomes compared to passive learning, such as traditional lectures without interaction. However, it is also demonstrated that it is not necessarily the case that the more collaborative learning there is the better. A combination of different methods might be the best (Prince 2004).

It has been a longstanding interest for researchers and teachers in physics education to develop the students' problem-solving skills. The process for problem solving has been described on an individual level, especially for a closely related subject such as mathematics (Polya 1957; Schoenfeld 1985, 1994), but also for a general purpose (Gick 1986) and reviewed for physics (Maloney 1994).

However, there has not been any substantial research on the problem-solving process in group work in physics and what influences such group work. It has been reported that group work gives better conceptual understanding compared to individual

problem solving (Heller et al. 1992). This understanding includes usefulness of physical description and matching of physical description with physical concepts and principles in mathematical expressions. But it has been argued that this has not been formally tested (Huffman 1997). However, Harskamp and Ding (2006) demonstrated how structured collaborative learning improves problem solving in physics more than individual learning does. In that comparative study it is also proposed that the discussions of the students should be traced and explored in future studies.

Several studies have been conducted to map out how interaction is visible in small-group work in physics and how the groups can be managed (Berge 2011; Heller and Hollabaugh 1992; Stamovlasis et al. 2006). Studies have also been conducted on the question how the use of context affects the students' interest and how the use of context-rich problems (Heller and Hollabaugh 1992) develops the discussion from talk based on everyday life experiences to a conversation based on physics reasoning (Benckert and Pettersson 2008; Benckert et al. 2005; Enghag et al. 2007, 2009; Enghag and Niedderer 2008; Jonsson et al. 2008). This paper adds to the knowledge of group work, aimed at context-rich problems (CRP) in physics, by studying the problem-solving process in student groups.

2. Aim and research questions

Even though collaborative learning settings are quite common in physics teaching there is still a need for more research on the problem-solving process at a group level.

CRP has proven to be a functional pedagogical tool for physics students, but there is still a need to add knowledge of how the problem-solving process evolves. In this study we have followed the steps for five student groups when solving context-rich problems in physics. The aim is to develop an empirically based guide for teachers how to work

with students in small groups on problem-solving in science and engineering. Two main research questions will be explored:

- Can a path be observed regarding students moving between different problem-solving categories when working in groups?
- If so, can these moves be related to specific episodes in the group work?

3. Theoretical framework

To build a theoretical base for this investigation we have looked into research on problem solving in physics, how the process can be described and what is highlighted as crucial points. Also a reliable and suitable method of analysis must be presented.

3.1 Intellectual tool for problem-solving

Research on how problem solving is conducted has been an active field for a long period of time. A review of how experts differ from novices in problem solving can be found for examples in Chapter 2 of *How people learn* (Bransford et al. 2000). The fact that an expert solves problems faster and more stringently rigorously than a novice is not to be explained by talent or intuition (de Groot, 1965).

In the area of problem solving in physics Larkin, McDermott and Simon (1980) have concluded that this skill is based in the expert's considerable domain knowledge including schemata for interpretation and solution of problems and a large number of patterns that function as a fast guide to relevant aspects of knowledge. This knowledge and these patterns are archived through processes that must be exercised over considerable time. To become an expert problem solver, therefore, involves a time-consuming process to conquer knowledge and build mental structures and patterns to make the retrieval of that knowledge fast and easy.

Besides speed and accuracy in the problem-solving process Larkin, McDermott and Simon (1980) found that a novice often solved a problem backwards, from the unknown solution to the known and given quantities, while experts solve problems forward, from given parameters to unknown quantity, at least for easy problems. This result followed the results from Simon and Simon (1978) who also argued that the physical intuition was a matter of quality in problem representation. The backward problem solving by a novice is seen as opposed to the forward strategy used by experts where the expert, starting out from firm knowledge of the laws of physics and solution principles, has schemes available to work directly towards the problem goal based on the given information (Chi et al. 1981).

To solve a problem one should first generate a problem representation, which includes extracting given information and formulating a goal for the problem (Gick 1986). Here the problem-solver connects the problem to existing knowledge in the mind and a scheme of how to proceed can be activated. A solution process following a scheme is typical for an expert, while a novice has to choose a search strategy in which looking for more information, similarities with problems solved earlier and comparing goal state with problem state are more typical.

After the representation stage there is the solution process. If the problem solver runs into difficulties here he or she has to redefine the problem representation or enter the novice search strategy described above. After a successful solution there may also be a check of the solution. It is to be noted also that there is no rigid separation into different stages. The problem-solving process may involve looping back to a previous stage.

Problem solving in general has also been presented by Bransford and Stein (1993). They use a five-step scheme easy to remember through the acronym IDEAL: 1)

Identify the problem and opportunities [to do something creative], 2) Define goals, 3) Explore possible strategies, 4) Anticipate outcomes and act! The final step is 5) Look back and learn. This scheme for problem solving has been used before to analyse the problem-solving process in collaborative student groups (Lamm et al. 2012) and is also applied in this investigation. We can identify the first three steps as part of the representation stage that can thus have several parts, while the fourth step is the solution step according to Gick. The fifth step can be identified as the optional check of solution that Gick describes but also as a part where you build a knowledge base for future problem solving.

Backward moves in the problem-solving process do not necessarily have to define a novice problem solver. As Gick (1986) points out, problem solving is not always a one-directional process even for experts. This is also indicated by Reif (1995). An experienced problem solver can be obliged to develop a search strategy, including the definition of sub-goals, even though this is more frequent among novice problem solvers. For an expert these moves are intrinsic to a problem-solving scheme and not induced as for the novice. However, Priest and Lindsay (1992) found that both experts and novices exhibit a forward interference when solving physics problems, even though experts are more competent than novices when it comes to planning the solution before solving the problem.

3.2 Conditions for group work

On a group level one must also be aware of the conditions for the group to work, the interplay within the group and the functionality of the group. Competence and gender are among the important parameters for this interplay. Several studies have been conducted regarding these aspects of group work in physics (Berge 2011; Due 2009; Jonsson et al. 2008; Ding and Harskamp, 2006; Heller and Hollabaugh, 1992).

It is also proposed by Roschelle and Teasley (1994) that for group work a shared problem-solving structure, called the Joint Problem Space (JPS), supports the problem-solving process. This structure is formed by the integration of activities related to problem-solving steps: goals, descriptions of the current problem state, awareness of available problem-solving actions, associations that relate to goals, features of the current problem state, and available actions. Problem solving is thus not only an activity in the individual mind, but also a collaborative arena: the JPS, constructed by language, the context and the students' activities.

3.3 Ways to expertise

Even though a skilled problem solver in physics at the introductory level at university is supposed to be able to solve problems single-handedly, he/she has to develop to reach this level, usually through teaching. To help students to develop functional problem-solving skills, most physics textbooks on the introductory level present strategies for problem solving. See for example *Physics for Scientists and Engineers* (Tipler and Mosca 2008), *University Physics with Modern Physics* (Young and Freedman 2012) or *College Physics, A Strategic Approach* (Knight et al. 2010). Here schemes are presented to solve textbook problems and they all follow a scheme compatible with Gick (1986) and Bransford and Stein (1993). We can therefore assume that most physics students at university level have encountered a presentation of problem-solving methods in their course of study.

A model of teaching and learning, based on research in physics education and with a structure that includes training in problem solving, has been proposed (Becerra-Labra et al. 2012). This model emphasizes discussion and quantitative analysis, rather than finding an equation where values of parameters can be plugged in. Results from the

use of this model showed that students developed scientific reasoning habits as part of their problem-solving skills.

4. Design and Method

4.1 Text-book problems and context-rich problems

It is common to use traditional end-of-chapter text book problems to develop problem-solving skills at university level. These problems are usually limited to a well-defined domain in physics, a definite question is posed, one correct solution method is applicable and only one correct answer exists. Over the past few decades, however, the question has been raised whether text-books problems are fostering a concept understanding of physics (Heller, Keith and Anderson 1992, Sefton 1993).

To develop learning in physics, context-rich problems (Heller and Hollabaugh 1992) have been proven to be functional. This way of presenting physics problems involves a method of forming functional student groups, presenting a scheme for problem solving to be used by the group and formulating a specific way of constructing and writing physics problems that invites the students to discussion and involvement.

A CRP is written as a short story which defines the student as the main character by using 'you' as personal pronoun. The story has to be credible and set in a real context to motivate the students to solve the problem. If assumptions and approximations have to be made for the solution, they are not explicitly given but have to be carried out by the students. The problem can contain unnecessary information or information can be missing, for the student to find. It should be so complex that it cannot be solved in one step. Also, what has to be calculated does not need to be explicitly asked for.

This way of presenting the problem is meant to generate discussions among the students. It has been demonstrated that tasks appeal to students through being put also in a relevant context (Benckert et al. 2005; Rennie and Parker 1995).

4.2 Context-rich Problems to solve

In this investigation student groups are given the task of solving two different CRPs.

They are presented here together with problem-solving considerations.

The Telescope Problem

You are studying the stars with your telescope and have it set so that the image of the stars is generated 12 meters behind the lens. The lens has a diameter of one meter. In the corner of your eye you see a plane coming in from the right at about a kilometer altitude. You point the telescope toward the aircraft to look at it, but will have to adjust the telescope to get a sharp image. How far from the lens is the image created and how big is the image of the aircraft compared to the real plane?

Figure 1. The Telescope Problem, one of the context rich problem used in the study.

The Telescope Problem (see Figure 1) is rather straightforward to solve when one have identified useful models or equations describing imaging and magnification in optics.

The imaging is given by the lens formula, where the distance to the object, the distance to the image and the focal length for the lens are the parameters. From this the magnification, as the ratio between the two distances mentioned, is calculated. An alternative to calculate the magnification is the ratio between image size and object size.

However, one have to negotiate with ones fellow students regarding what values should be used for the parameter. The problem is hence an open-ended problem (Potts

1994). To solve part of the problem one also have to use data calculated from the star observation mentioned in the problem.

The Drink Problem

You are with a friend at the “Gondolen” restaurant in Stockholm and have just ordered a drink before dinner. While you are having the drink and looking at the “Stockholms ström” river, your friend is philosophising: - Are you as a physicist able to tell me how many ice-cubes are needed to cool this drink to an appropriate temperature?

Figure 2. The drink Problem, the second context rich problem used in this study.

Even if a goal is stated in The Drink Problem (see Figure 2), the amount of ice, preferably given in weight, this problem is also an open-ended problem since no volumes, masses, temperatures or other data are given. One also have to negotiate with the other members of the group what ‘suitable temperature’ means and hence no single correct answer exists. As a student one would also probably like to simplify the drink to a glass of water to set up a model that is relatively easy to apply.

An expert can recognise this as an equilibrium problem in calorimetrics, a part of thermodynamics. Based on this knowledge a model can be made in the form of an equation, including the mass of the ice, the goal. The final equation to solve the problem states that the energy entering the ice, to raise the temperature of the ice to zero degrees Celsius, melting the ice and raising the temperature of the water from the melted ice to the final temperature, is equal to the energy removed from the drink (water) when lowering its temperature to the final temperature.

This equation states what parameters must be estimated, such as the initial temperatures of the drink and of the ice, what the final temperature should be and also

what assumptions must be made. Such an assumption can be that there is no heat exchange between the mixture and the surrounding glass or air.

For an expert it is probably a one-step equation but for a novice one can anticipate several steps according to the time stages in the physical process. These will be the rising of the temperature of the ice as it is added to the water, the melting of the ice and finally the rising of the temperature of water from the melted ice. In parallel with this the temperature of the original water will decrease until the two temperatures meet.

The Drink Problem has been investigated earlier in terms of discussion patterns and the development of physics reasoning (Enghag, et al., 2007) and in terms of group dynamics and the students' own experience of the problem-solving process (Jonsson, et al., 2008). In this paper we focus on what we as researchers observe related to a problem-solving scheme.

4.3 Student Groups and Procedure to Produce Data

Five groups of three to four students each have been video recorded when solving the CRPs in physics described above. The research in general and the video recording procedure especially are following ethical standards (Hermerén 2011). The students in the groups are all part of a cohort of approximately 50 students admitted to a 3-year Aeronautical Engineering study program. All groups consisted of male students as a result of few participating female students in the study program and none of them was placed in these groups. Thus no gender issues could be investigated.

The students are studying in their first year, have known each other for approximately two months and taken two courses together already. In this study they are all taking an introductory physics course of 7.5 ECTS (European Credit Transfer

System) credits. In the course 40 per cent of the teaching time was used for traditional lectures and 20 per cent for laboratory experiments. In addition to this, three 135-minute meetings were used for solving CRPs and the same amount of time for other exercises, such as problem-solving of end-of-chapter text book problems, both by the teacher and individually. Thus, the students are introduced to a problem-solving scheme in class before meeting the CRP. Approximately 20 per cent of the total time in the classroom was used for CRPs. The CRP solving was a compulsory part of the course but to participate in this study was voluntary.

The groups were formed in accordance with suggestions made by Heller and Hollabaugh (1992) on the basis of the students' previous performance. In this investigation this performance was equated to the results from an introductory course in mathematics in their engineering study programme. Each group consisted of at least one student performing above average, one around average and one below average in mathematics. The students were not informed how the groups were formed by the teachers. The students were familiar with the concept of working in groups at the university level since they did collaborative work also in the mathematics course they took ahead of the physics course. The groups worked as teams, without prescribed duties for specific members within the group, and can therefore be described as collaborative groups.

The teachers (usually one teacher, but two of the authors for this study) visited the groups once or twice during the problem-solving process. The purpose of these visits was mainly to control that there was a progress in the problem solving and that the groups did not get stuck in difficulties. Over the course of this intervention case study, the teachers did not help the students in the problem solving at any time.

Two of the groups solved The Telescope Problem, Group 1 and Group 2 below. The other three groups, Group 3 to Group 5, solved The Drink Problem. The problems took between 25 and 45 minutes to solve for the groups. The Telescope Problem took a little less time than The Drink Problem. The student groups were video recorded during the problem-solving process and the recordings were transcribed verbatim.

4.4 Data Coding, Reliability and Method of Analysis

The transcripts were used to map out the problem-solving stages along a time line in accordance with the five stages or categories of the IDEAL-model by Bransford and Stein (1993). Each utterance has been coded to one of the five problem-solving categories or a category named 'Other'. The 'Other' category contains everything irrelevant to the solution of the problem such as making jokes, asking questions not related to the problem-solving process and utterances from the teacher.

We coded the interaction with the teachers as 'Other' since they do not interact with the solution process in any way to affect the outcome. A teacher visited the group once or twice before the group presented their solution. These visits lasted for one minute or less.

For each category several indicators have been identified based on the transcript in relation to the categories that we have looked for. These are presented in Table 1.

<i>Category</i>	<i>Indicators</i>
Identify the problem and opportunities	<ul style="list-style-type: none"> • Talk about what area of physics the problem belongs to • Drawing figures and talking about them on a general plane • Referring to lecture notes, text-books, exercises or similar problems solved earlier • Talk about equations that one can use • Discussion of concepts

Define goals	<ul style="list-style-type: none"> • Talk that raises questions of the goal or defines a goal that they plan to calculate
Explore possible strategies	<ul style="list-style-type: none"> • Discussion of relevant equations • Discussion of parameters in these equations • Discussion of values for parameters to use
Anticipate outcomes and act!	<ul style="list-style-type: none"> • Doing calculations • Goal-related statement such as ‘this calculation will give the answer’, ‘the answer is...’, ‘now we know that q equals...’ • Verbalising a result
Look back and learn	<ul style="list-style-type: none"> • Discussing the problem solving they have done • Questioning whether the answer is reasonable, in magnitude and dimension. • Talk about whether the answer found really is the goal

Table 1. The categories and corresponding indicators used in the analysis.

One researcher coded each statement, 589 in total of which 485 belonged to one of the IDEAL-categories. The remaining 104, or 17.7 % of the total, belonged to the category ‘Other’. For the five groups, the category ‘Other’ was between 5.4 and 38.7 % of the total amount of statement per group. After this categorization, another researcher validated the codification by performing his own codification of 111 statements or 13 % of the statements. To investigate the interrater reliability a consensus estimate was calculated through the ratio of the number of codified statements where the researchers are in agreement, divided by the total number of statements that both of them codified (Stemler 2004). The agreement between the two codifications was 80.4 %, which is well above an acceptance level of 70 % for validity (Stemler 2004).

The results for analysis are both the transcripts and the codified statements. The latter is summarised in three sets of diagrams. The codified problem-solving process is

presented as a total number for the activities under each IDEAL-category for each student group, see Figure 3. This figure gives a total picture or overview of the problem-solving process, demonstrating in which categories the students were most active.

From the transcript, the time line has also been divided into five-minute slots and for each slot the total number for each category has been computed and is shown as a bar diagram in Figure 4. From these diagrams one can follow over time in which category the main activities take place in a specific time slot. The bar diagrams in Figure 4 for each CRP give a visual picture of the major shifts in problem-solving moves between the different categories in the process for the groups. In Figures 3 and 4 the vertical axis gives the percentage per category of the total number of identified utterances, while on the horizontal axis the different categories are presented.

To map out the moves between the problem-solving categories for the collaborative groups, we have used Schoenfeld-inspired plots (Schoenfeld 1985), but instead of the activity categories used by Schoenfeld we have used the problem-solving categories from Bransford and Stein (1993) as representation. See Figure 5, in which we have also included the corresponding transcript to present the data for the category codification. This diagram displays activities of the student group in terms of IDEAL category versus a time axis.

Kohl and Finkelstein (2008) have introduced what they call a complexity parameter as a numerical parameter for studying the complexity in a Schoenfeld diagram, more specifically the number of transitions presented by the diagram. All moves between different categories, within the IDEAL model, were counted. The complexity parameter then serves as a count of the number of category transitions present. Kohl and Finkelstein constructed a sequence diagram for the count of the complexity parameter, while we calculated the total number of moves within the group

from the Schoenfeld-inspired plots. See Figure 5 as an example and Table 2 for the complexity parameters for the groups.

For an expert, who single-handedly solves a problem in a process described by the IDEAL-model, the lowest possible complexity parameter is four, the number of moves between the categories in sequence. For a novice problem solver who has to back-loop in the problem-solving process a higher complexity parameter will be reached. This also applies if there is a group with members posing questions to each other that have to be dealt with and that lead to revisiting categories in the problem-solving process.

5. Results and Analysis

5.1 General Features and Differences

As can be seen from Figure 3 all problem-solving categories are represented for all five groups. The appearances of the relative number of marks per category have both similarities and differences. The category ‘Identify the problem’ can be expected to have different value regarding marks in the codification between the groups, depending on existing knowledge and experience in a group. Furthermore, since both problems investigated are to some extent open with non-identified parameters or no values given for them, the ‘Explore’ category can be expected to be rather large.

Figure 3. The percentage of utterances related to the five problem-solving categories (IDEAL) for the five student groups studied is shown with one diagram per group.

For four of the groups the 'Identify the problem' category and for all groups the 'Explore' category are the top two categories based on how many times they have been identified in the transcripts. The exception here is Group 1 and the former category, which has a very low number of marks. However, this does not necessarily mean that this group did a less thorough job when identifying the problem. If one looks at Figure 4 which indicates the moves between the categories, it is obvious that Group 1 spent time in this category, 'Identifying the problem', at the beginning of the problem-solving process but also that they returned to this category later, indicating that an unresolved part had to be dealt with.

In the problems, the goal to calculate can be seen as rather easy to describe and to reach an agreement about in a discussion among the students. Therefore the corresponding category, 'Define the goals', could be expected to be less dominating. Also, when a mathematical model based on a relevant area of physics has been found or derived, the 'Act' category could be expected to give less frequent marks in the coding process. These anticipated outcomes are also to a great extent apparent in the results.

When looking into the problem-solving moves in Figure 4, a time-restricted dominance appears for each category that describes a problem-solving time flow through the categories as: $I \rightarrow D \rightarrow E \rightarrow A \rightarrow L$. All the same, any other overall pattern besides this is not obvious. Instead one can see that within a time slot everything from one category to all five can appear. One category early in the problem-solving scheme such as 'Identify' or 'Define the goals' can reappear later in the process after being absent in one or several time slots. This can be seen as indications of several aspects such as the complexity of the problem and patterns of novices.

Figure 4. The distribution in percentage of the total amount of utterances presented within 5-minute slots for three of the five groups. Group 1 and 2 was solving the Telescope Problem, while groups 3 to 5 were solving the Drink Problem. In each five-minute slot all IDEAL-categories are presented.

For Group 3 to 5, solving The Drink Problem, the problem-solving moves were not as frequent within each five-minute slot as for the groups solving The Telescope Problem. While the groups solving The Telescope Problem often had three to four categories represented in each time slot, with a mean value of 3.5 categories for all slots together for this problem, the groups solving The Drink Problem had approximately one less. The mean value here is 2.3 categories per time slot.

A similar difference also appeared for the complexity parameters for the groups, Table 2. Two values stand out: the high value for Group 2 (The Telescope Problem) and the low value for Group 3 (The Drink Problem). We will below present and describe the results per category in the problem-solving procedure in greater detail.

<i>Group/problem</i>	<i>Complexity parameter</i>
1/Telescope	30
2/Telescope	49
3/Drink	21
4/Drink	27
5/Drink	36

Table 2. The complexity, total number of moves between different problem-solving categories, for each group.

5.2 The Category ‘Identifying the Problem’

Group 1 (The Telescope Problem) differed regarding the ‘Identify’ category from the other four groups investigated (see Figure 3). For this group we registered a low number

of marks and when studying the transcript for this group a picture appeared in which the group was rather focused on finding ‘the right equation’. They directly understood the topic and area of physics, which is optics, and rapidly looked into their textbook for an applicable equation. After just over five minutes on the video recording one of the students points to an equation in his book and suggests the use of it. This can be seen as an example of placing the focus on calculating an answer, typical for novices (Johnson 2001). Through identifying a suitable equation, Group 1 could quickly go on to talk about goals, discuss values of parameters and make a calculation. This speedy progress is also seen in Figure 4, in which this group in the second time slot (five to ten minutes) already covers all five categories in their talk and also in the third time slot have marks for four of the categories.

Group 2, that was solving the same problem, was not able to identify a suitable equation as quickly as Group 1. From the transcript we have this utterance during the first five minutes:

Student 2.A: I am thinking of the stars, should one start calculating the distance to the stars? That is what I can see. The fact that the lens has a diameter of one metre, that cannot matter.

Student 2.B: No.

Student 2.D: I think it can.

Student 2.A: Yes, one thinks like that, one thinks about some equation or something. But there are no equations with diameter, [for] the lens I mean.

Here we can see how the students struggled in trying to decide what matters: Is the distance to the stars of importance? The diameter of the lens is given, insignificant information for this problem, but with this information given they thought that it must be used in the calculation. The transcript indicates that the students did not have a solid

knowledge base. They could not see what matters and what is needed for them to be able to solve the problem.

This analysis is supported by the fact that Group 2 returned to the non-existing problem with the lens after nearly ten minutes from the start, where all students are involved in the discussion and again after 22 minutes.

This is an example of how irrelevant information disturbs the problem-solving process when a lack of solid knowledge means that the students cannot exclude the unimportant parts in the problem. Because the students were all novices who lacked such knowledge, the problem-solving process for all groups moved back and forth between the categories, see Figure 4 and Figure 5.

Time	Student		I	D	E	A	L
06:53	1.B	What is it that we want to know? It is b that we want.					
07:00	1.A	[Reading the problem] How large will the image be? How large?					
07:10	1.B	It is the same thing as -q.					
07:20	1.B	What can one say? It is the same thing as, times y0 and you get it.					
07:35	1.B	The easiest is to calculate where the image will appear. That we can do directly.					
07:45	1.C	Then we must look on the stars. It half...					
07:50	1.A	Compaire position, for image and stars.					
08:00	1.B	The star one can ragarded as far away, the image will end up...distance					
08:10	1.A	It is q we are looking for					
08:20	1.B	One can solve q.					
08:25	1.A	Then q equals f.					
08:30	1.B	Right, then we know that.					
08:35	1.A	Then we know that.					
08:45	1.B	Then we know that it is two meters behind the lens, in the focal point					
09:00	1.A	What? Is it here? [Points on the board]					

Figure 5. The Schoenfeld-inspired plot for Group 1 (Telescope Problem), showing moves between the different problem-solving categories for just over two minutes. The cumulative complexity parameter for this period is 9.

As a summary we noted a focus on finding the ‘right equation’ in the groups and some problems in sorting out what was important or not in the information given. These features are typical for the novice problem solver.

5.3 The category ‘Define goals’

Group 1 (The Telescope Problem) had a rather large category ‘Defining the goal’ but the transcript shows that this was actually not a result of discussions to identify the goal. Instead they confirmed the goal again and again to one another. At the time 10:25:

Student 1.A: Then we can do it... Yes, that is the distance to the image. That is what we want.

Student 1.B: (writing on the board)

Student 1.A: The distance to the image, right?

Student 1.A and 1.B pointing on the board: This is what we have to calculate.

Conversations like this occurred in three of the five time slots, see also Figure 4. In Group 3, which was one of the groups solving The Drink Problem, the category ‘Define the goal’ was rather large too. We can see in Figure 4 that this category occurs in five of the eight time slots. One student, called 3.B, defined the appropriate goal – the amount of ice needed to cool the drink – after 7 minutes, but his peers had difficulties in grasping this. They had to return to the goal formulation several times. After nearly nine minutes Student 3.C says ‘I think that we should write down what is happening as the

answer', which indicates that the student had problems in understanding the assignment. After 11 minutes students 3.A and 3.B agreed that it is the mass of the ice that has to be calculated. Student 3.C did not participate in this discussion but read the problem. After eleven and a half minutes he involved student 3.B in this line of thought:

Student 3.C: I wonder what a suitable temperature can be (given in in the problem as the final temperature for the drink).

Student 3.B: Refrigerator cooled.

Student 3.C: But then the ice will melt. I wonder what [the problem writer] means with a suitable temperature.

Here we can presume that student 3.C was stuck in his everyday experience of a drink with ice in it and could not relate to the calorimetrics in the problem. After 27 minutes, when the calculations reached the final stage, student 3.A was unsure of the goal and pose if 'it [is] m (the mass of ice) that that we have to solve in the equation?', which is positively answered by Student 3.B. While student 3.A worked to grasp the goal, student 3.C never indicated that he has understood how it was formulated or was calculated.

As examples of how a lack of appropriate physics knowledge leads the discussion into irrelevant paths for problem solving, but still helps to build up a knowledge base, we have discussions from Group 4, solving The Drink Problem. Initially they agreed that it is the amount of ice that is the goal to calculate. One of the students even proposes that they could calculate it as one ice cube, since it is the mass that matters, the goal to calculate, not the number of ice cubes. However, after four minutes another student said:

Student 4.A: I think it's a poser regarding the number of ice cubes. A lot of ice chills faster. Then all the ice doesn't melt.

One and a half minutes later another student picked this up:

Student 4.D: Doesn't it matter how many sides there are [on the piece of ice]? Do you understand what I mean? If the ice is in contact with the liquid? If you have only one piece or a lot? It will be quicker with a lot of pieces, but it is only the speed.

However, they managed to leave this discussion since they agreed that the speed of the chilling process does not affect the final temperature.

For this category we saw that the goal sometimes has to be re-established in the groups even if they all initially agree on it. Also the problem to relate the everyday world to the world of physics was obvious.

5.4 The Category 'Exploring Possible Strategies'

This category was large in all the groups and even dominated in some. It accounted for between 25 and 50 per cent of all problem-solving activities.

In the category we found examples of both a lack of physics knowledge and an interesting view of everyday knowledge. This was noted after 10 minutes in the same group as above, Group 4 (The Drink Problem). They were here looking for parameter values for the specific heat of water and ice in tables to use in the calculations. Student 4.D found them and told student 4.B who wrote them down. The specific heat values were given for defined temperatures. Student 4.A got puzzled:

Student 4.A: Can ice be colder than 0°C ?

Student 4.D: Yes, it is given for minus 10 in the table.

Student 4.A: Then it depends on how cold the freezer is.

Student 4.A lives in a country that experiences winter every year, often with temperatures well below zero with snow and ice. Despite this experience he had not reflected upon whether the temperature of ice can be below zero, and when it was brought to his attention he related it to the temperature in the freezer, not the winter climate. The same also went for student 4.D, as he exemplified with data from the table, not from his own experience of winter or common sense.

For the groups that were solving The Drink Problem, Group 5 could appear as a bit odd since they started formulating a model, an equation to use, in the first time slot already without talking about the goal, see Figure 4. We interpreted this as a result of their fast recognition of the relevant physics topics and the identification of a possible equation to use. After just a little over a minute they had recognised a similar problem that they had solved in class and now they knew what the basic equation to use was.

Only then did they realise that they must understand which parameter in the equation it is their goal to calculate:

dQ was, well... What is it that we have to find out?... Ice cubes

Here dQ , the change in heat, is one side of the equation that they have to use. But the equation also includes other parameters. Among them is the goal, the mass of the ice that they have to calculate.

5.5 The Category ‘Anticipate Outcomes and Act!’

The fourth category, ‘Act!’ is rather small for all groups. This seems reasonable since when a suitable model to apply has been found and you have reached agreement regarding values for parameters, the calculation will be rather straightforward. Here,

however, we see that Group 1 has spent a relatively large amount of time here. It was the second largest category for them, compared to being the smallest or second smallest in the other four groups.

In the transcript we saw that there were always two students in Group 1 doing calculations in parallel, holding a conversation about what they were entering in their calculators. We found this as the reason for the large number of marks.

5.6 The Category ‘Look Back and Learn’

For this category we found in Group 2 (The Telescope Problem) how intuitive knowledge came into use for forming a context of understanding (Sherin 2006). After about 17 minutes the students had calculated the size of the image of the aeroplane, and entered the fifth category, ‘Look back and learn’, with this discussion regarding the image:

Student 2.A: A reduction also. That doesn’t sound good.

Student 2.C: What’s next? (Eager to continue the problem solving)

Student 2.B (to student 2.A): Why not?

Student 2.A: Personally...

Student 2.D: Yes, but the plane gets enlarged. No, but...what the heck? It should be enlarged.

Student 2.D now realised the dilemma: he was expecting an enlargement but the calculated answer was a reduction in size of the image of the aeroplane. They continued:

Student 2.A: I think so. It is like a magnifying glass (shows how one is used). It is the same principle. You don't reduce [an image] with that, do you?

Student 2.B: Yes, but it is in relation to the real image (he means object).

Student 2.A: And it (the image) ends up at this position. Then it is totally enlarged if you think like that.

Student 2.B: If you have binoculars and watch a seagull when you are out on the sea, then it is small at first, when you look at it at a distance. But if you move the image here (shows with his hands) it is not small.

Student 2.A had a conflict between the result and his intuitive knowledge and student 2.B tried to resolve it based on his intuitive knowledge. Student 2.A never succeeded in resolving his dilemma but he was aware of having it. It is not satisfactory but better than ignorance.

6. Discussion

The overall impression, as seen in Figure 3 with 'Identify the problem' and 'Explore possible strategies and opportunities' as dominating positions in the number of marks while 'Define goals' and 'Anticipate outcomes and act!' are considerably smaller, is rather expected, and exceptions to this general result are understandable when analysing the transcripts. For Group 1 as example with few marks in 'Identify the problem' we found a strategy building on finding the 'right' equation, which led to a high value of 'Define goals'. The frequent returns to this category indicate difficulties to grasp the problem. If we look into the problem-solving process on a time scale, the five-minute slots in figure 4, we can see that the five problem-solving categories used each have a dominating period in the process.

On an even more detailed scale, Figure 5, we find an iterative process or backward moves, where earlier stages in the problem-solving process have to be revisited, to identify sub-problems, give parameter values or even restate the goal. This is a substantial feature characteristic for all groups and we value it with a complexity parameter. The observed iterative action in the problem-solving process results from the fact that the students have not developed a broad experience, including a knowledge base with a connecting problem-solving scheme. Another influencing factor is that the everyday experiences of the students do not fit in with the models or results.

For a researcher it is quite straightforward and easy to identify and follow the problem-solving moves in the cooperative groups as they use so much language, both spoken and corporeal. However, this observation is valid only if the studied group is functional in the sense that it has internal communication, that the group members work together as a team and that they see one another as peers.

Some special features that led to discussions among the students are prominent in the results. Such features belonging to the construction of the problem are inclusion of irrelevant information and lack of information, for example values of some necessary parameters for calculation. It is also obvious that some students interpret all the information given in a problem as relevant to use.

The students themselves also developed the discussion in the problem-solving process with contributions from intuitive or everyday knowledge. We found that parameter values or results that do not fit in with their view of the world were introduced into the discussion. This appears in the discussion when the size of the image is a reduction compared to the object size and not an enlargement. However, in a collaborative group, students who experienced such problems got help from their peers in the hope of sorting them out.

In this cluster of discussion-generating items we also include the lack of ability to recognise everyday experience. One example is that ice that can be cooler than zero degrees did not seem to be obvious. Another uncertainty that generates discussion is the difficulty to formulate the goal or the need of restating the goal, which happened in some of the groups. The results presented situations where students have their own position in the solution process and can raise questions regarding any uncertainty which generates discussions.

The frequent moves back and forth between different categories in the problem-solving process are also manifested in a high value for the complexity parameter and not a low one as for experts (Kohl and Finkelstein 2008). We interpret the frequent moves, and the high value for the complexity parameter that follows as a result from the collaborative work and the construction of the context-rich problems. This promotes discussions which offer the potential to develop knowledge and skills together with peers, but these discussions are also depending on the socio-dynamic situation in the group.

The discussions in the groups and the observed moves between the categories in the problem-solving process we argue constitute evidence of the Joint Problem Space (Roschelle and Teasley 1994) and we have found it to be present in all five groups. JPS includes observable activities such as language and gestures related to the problem-solving activities. Within this space the participants challenge opinions, broadening their knowledge base and developing problem-solving skills together.

We also observe that the JPS space can be said to have different 'volume' described by the value of the parameter of complexity. For example, in Group 3 (The Drink Problem) one student acted alone and solved the problem more individually, compared with the activities in the other two groups solving this problem. This action is

also described by Jonsson et al. (2008) for this group and the behaviour can obstruct the possibility for all the group members to participate in the problem-solving process. Talk in Group 3 was initiated by another student, while the third rarely interacted.

In the other groups the discussions were based on more equal positions. This difference between the groups was manifested in this study as Group 3 being the one with the lowest value for the complexity parameter, see Table 2. Thus a low value for the complexity parameter can indicate that a skilled problem solver is at hand but also that the interaction and dynamics in the group are low.

Of course it is not straightforward to compare values for the complexity parameter between different problems but a generally higher number for one problem compared to another problem can indicate a higher level of difficulty in such a problem. Regarding the value for the complexity parameter for different groups solving the same problem one can argue that differences in the value for the complexity parameter can be an indicator of the collaboration in the groups.

7. Conclusions and Implications

Collaborative work with CRPs is an exercise that includes training of the problem-solving ability in physics for engineering students. It also gives possibility to enhance their group work competence, both skills which will be valuable in their future professional work.

In relation to our research questions we have found that a clear path describing an iterative process can be observed for the moves in the problem-solving process through the five IDEAL steps presented by Bransford and Stein (1993). This indicates that not only individuals but also the collaborative groups have a problem-solving path.

The moves between the categories, forward and backward in the problem-solving process, are more likely to occur if irrelevant information and lack of parameter values are part of the task. These kinds of problems give the students opportunities to use their own experience to discuss the values of the parameters and recognize that these are not given in the problem text. It is also valuable if the students can evaluate the answer in relation to their everyday experience. Through doing so they will get an opportunity to develop an understanding of physical models or at least realise that their meaning making is incomplete.

One finding with implications for teaching is that meaning making often occurs in dialogue with other students. It is important that the students are comfortable with discussing their everyday experience related to the problem and solution and that they all allow each other to participate in the discussions.

Another important finding with implications for teaching is that if one student is ahead of the others and tries to move the problem solving to the next category in the model, the others can raise a question regarding some uncertainty that generates a discussion. This slows down the process, as seen as backward moves in the IDEAL-model, and offers an opportunity for each and every one to level with the others in the problem-solving process. The more competent student has to verbalise a standpoint, to explain, which seems to be beneficial for all. The fact that the discussions slow down the progress in problem solving, leads to everyone having a better possibility to grasp aspects of the problem and acquire a knowledge base.

It has been found by Lamm et al. (2012) that differences in the problem-solving ability of collaborative groups in agriculture studies can be related to an individual cognitive style. The values for the complexity parameter in our study indicate that there are differences also between groups solving physics problem. It remains to investigate

how the composition of the groups, the socio-dynamics of the groups and also the difficulty of the problem affect the problem-solving process.

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