Structured Collaboration versus Individual Learning in Solving Physics Problems

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Structured Collaboration versus Individual Learning in Solving Physics Problems

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The research issue in this study is how to structure collaborative learning so that it improves solving physics problems more than individual learning. Structured collaborative learning has been compared with individual learning environments with Schoenfeld's problem-solving episodes. Students took a pre-test and a post-test and had the opportunity to solve six physics problems. Ninety-nine students from a secondary school in Shanghai participated in the study. Students who learnt to solve problems in collaboration and students who learnt to solve problems individually with hints improved their problem-solving skills compared with those who learnt to solve the problems individually without hints. However, it was hard to discern an extra effect for students working collaboratively with hints—although we observed these students working in a more structured way than those in the other groups. We discuss ways to further investigate effective collaborative processes for solving physics problems.

Introduction

Computer-supported collaborative learning (CSCL) has become a promising tool in science education (Van Boxtel, 2000). Since collaboration is the process of interaction among peers in order to reach a common goal, it is very important that participants have a clear idea of proper ways to reach the common goal and how to contribute to it as an individual. Successful CSCL structures the collaboration process so that participants' motivation, personalities, prior knowledge, and experiences are combined in a coordinate group effort (Johnson & Johnson, 2000; Koschmann, 1996).

Much research on collaborative problem-solving with computers is about the conditions of collaboration, such as group size, group composition, nature of the

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task, or communication media and their impact on student learning. Dillenbourg, Baker, Blaye, and O'Malley (1996) expressed in their review of research the need to study the interactive processes in order to delineate which interactive processes may cause student learning. More recently research in CSCL has shown that the frequency of task-related interactions during collaboration is often a good predictor of learning outcomes of individual students. It is assumed that certain types of task-related interactions with others lead to the active processing of information by the individual, which can modify the individual's knowledge and skills. This is especially so when peers provide examples of a topic, explain a concept, demonstrate a solution method, or supply specific argumentation. These kinds of verbal interactions are called "elaborations". Elaborations between students are necessary to solve a problem collaboratively in such a way that participants improve their knowledge (Avouris, Dimitracopoulou, & Komis, 2002; Van Boxtel, 2000; Webb & Farivar, 1999).

Yet, it is difficult to trace how structuring of the learning environment effects the stimulation of elaborations between students and how this is related to learning outcomes of individuals. Even in structured CSCL environments students tend to spend much time on superficial aspects of the task rather than on elaborations. This may be due to the fact that students in CSCL do not see all of each other's activities, as in face-to-face collaboration, and feel they have to keep in touch. Hence, in this study we explore students' elaborations in face-to-face collaborative problem-solving and compare these with individual problem-solving.

Structuring Problem-solving

Science education in schools all over the world is increasingly required to produce high-order problem-solvers (UNESCO, 2004). As problem-solving is about finding a solution to a problem that is relatively new to the learner, it involves the skill to analyze a problem, to apply prior knowledge, to synthesize different bits of knowledge, to make decisions about how to proceed, and to evaluate the steps taken in the solution process (Polya, 1957). Many researchers have concluded that students may have the necessary prior knowledge for a problem but still cannot solve it (Sfard, Nesher, Streefland, Cobb, & Mason, 1998). While some students find it difficult to relate the right prior knowledge to the problem, others have difficulty analyzing a problem or carrying out the appropriate calculations. Based on a comprehensive review of research on problem-solving in physics, Maloney (1994) summarized that successful students' problem-solving strategies at least contain conscious qualitative analysis of a problem, making a sketch of the problem, restating the problem in one's own words, and conscious review of equations or theorems that fit the problem. The question for teachers is whether to teach students a step-by-step strategy or to let them construct a strategy on their own. Some researchers demonstrate that students will profit from a step-by-step strategy in solving problems independently (Heller, Keith, & Anderson, 1992). One example of the possibilities new technology provides is the intelligent tutoring program for solving algebra word problems designed by

Conati and Van Lehn (2000). Their program ANDES is showing a computer tutor that is coaching self-explanation when pupils follow the solution of example problems step by step. The program has a rather static view on how to solve problems and teach problem-solving through a procedure of fixed steps. But this procedure is not consistent with genuine problem-solving activity (Sfard & Kieran, 2001; Wilson, Fernandez, & Hadaway, 1993). In our study a five-episode strategy developed by Schoenfeld in solving mathematical problems was selected because of its suitability for solving problems in physics. According to Schoenfeld (1992, 1994) one should not dictate strict problem-solving steps but give students room for the development of an individual solving strategy using the following episodes:

- Read, analyze the problem (analyze).
- Activate relevant knowledge to solve the problem (explore).
- Make a plan (plan).
- Carry out the plan (implement).
- Check the answer (verify).

To make students conscious users of the episodes, Schoenfeld asked students procedural questions such as: Can you make a scheme of this problem? What procedure do you know that could help you? Have you made a plan? Did your solution answer the question? By asking these questions students reflect on their use of the episodes and develop self-confidence (Schoenfeld, 1994). Harskamp and Suhre (in press) developed a computer program for a mathematics course using the episodes of Schoenfeld's approach to help students solve applied mathematics problems. They provided hints in the computer program with each episode. The hints showed students how to act in the different episodes. The program was quite successful. Pol, Harskamp, and Suhre (2005) used the program to supports novices in solving physics problems about forces. The program does not dictate strict problem-solving steps and gives students room to develop an individual solving strategy. Hints are provided for the five episodes and the student may choose hints freely. The research showed that students who had worked with the program with hints could solve physics problems better than their peers who did the program without hints. In both research projects mentioned earlier, students hardly used the hints to verify their answers and on the post-test they had difficulty verifying their answers. So, in these projects, individual problem-solving with hints did not improve students' reflection on problem-solving. This needs special attention in the instructional design (Davis & Linn, 2000).

   We want to find out whether collaboration can improve students' reflection on physics problems. About 15 years ago Blaye, Light, Joiner, and Sheldon (1991) showed that children who had previously worked as collaborative pairs on problem-solving in physics were twice as successful on a knowledge test as children who had had the same amount of experience working alone. The researchers conclude that within a small group that works as a team, students tend to spend more time on reflecting and discussing the suggested solution than when students work individually. Nelson (1999) suggests on the basis of her research that if students are frequently engaged in constructive dialog, their knowledge of facts and procedures

will retain longer and their problem-solving skills in physics will improve more than if they learn individually.

However, collaborative learning will be at risk of becoming conversational learning and less effective than traditional learning if a structuring of interactions is absent. Without the presence of tutors, students are inclined to chat and become less oriented at their task. On the basis of their research, Erkens, Kanselaar, Prangsma, and Jaspers (2003), Pena-Shaff and Nicholls (2004), and Van der Meijden and Veenman (2005) suggest that structuring of the dialogs that students are supposed to have about the problem leads to more frequent higher-level elaboration and makes the process of knowledge construction in the individuals more effective. In structuring the collaboration process it is necessary to overcome impasses and redirect incorrect solution paths, to facilitate problem-solving interaction to keep students engaged, and to suggest how students can take the problem step by step. Students should find the optimal balance of peer interaction and take expert advice.

We think that the episodes of Schoenfeld's approach can provide suggestions of how to divide a problem into parts. By providing examples with each episode, students can take expert advice and can redirect themselves if they follow an incorrect solution path. We have evidence that this approach works for individual students (Pol et al., 2005). In order to make it work for learning in a group we need a script that tells the students how to maintain a balance between peer interaction and expert advice, and how to change between individual activities and peer interaction in solving a problem (Weinberger, Fischer, & Mandl, 2001). A script not only improves active participation of students, but can also provide knowledge convergence: finding common knowledge to carry out a task and socially sharing knowledge. Knowledge convergence among peers can be encouraged by shared resources such as hints, examples, and representations (Fischer & Mandl, 2002; Mancini, Hall, Hall, & Stewart, 1998; O'Donnell, 1999).

Schoenfeld's episodes with hints will show the students examples of high-level information they should provide as a result of their elaboration. The hints should be used after students have discussed their suggestions, prior knowledge, or solution plans. The hints provide feedback on their discussions and show students they are on the right track or provide students with knowledge they could not generate.

Research Questions

Under certain conditions collaborative problem-solving will be more effective than individual problem-solving. Students should know what to do and how to work together: some structuring of the process is needed.

In previous research with mathematics and physics problems, researchers concluded that episodes with hints to structure the solution process can improve individual problem-solving. But what if students working together on a problem are provided with episodes with hints? Will they improve their problem-solving skills still more?

From previous research very little is known about this issue. To explore the effectiveness of variations in structuring of collaborative and individual problem-solving, three research questions and hypotheses are formulated:

1. Does collaborative learning without hints improve students' problem-solving learning compared with individual learning without hints?
   Hypothesis 1: Collaborative problem-solving with the use of episodes leads to better learning outcome for individuals than individual problem-solving.
2. Does individual learning guided by hints improve students' problem-solving learning compared with learning without hints?
   Hypothesis 2: Individual problem-solving with the use of episodes and hints leads to better learning outcome for individuals than individual problem-solving with episodes only.
3. Does collaborative learning with hints improve students' problem-solving learning compared with collaborative learning without hints?
   Hypothesis 3: Collaborative problem-solving with episodes and hints leads to better learning outcome for individuals than collaborative problem-solving with episodes only.

Methodology

Experimental Design

In this research project the episodes of Schoenfeld's (1992) approach serve as stepping stones for problem-solving, and are used to structure students' learning processes. We have designed four conditions:

- A condition requiring students to collaborate on problem-solving with the help of hints (CL+H).
- A condition requiring students to collaborate on problem-solving without any hints (CL).
- A condition requiring students to solve problems individually with the help of hints (I+H).
- A condition requiring students to solve problems individually without any hints (I).

The study was conducted in a secondary school in Shanghai with a sample of 99 students from two classes of grade 11. The school ranked among the top-five best schools in Shanghai. Students in the study are at the age of 17, coming from families with a wide range of occupations, incomes, and educational levels. Of the sample, 54.5% were female ($n = 54$) and 45.5% were male ($n = 45$). The study was a randomized group design with a pre-test and a post-test. Students in each class were assigned randomly to the four conditions. Students in the two collaboration conditions worked in dyads. All students tried to solve the same moderately structured multi-step physics problems. We used new context problems that gave students ample opportunity to read and analyze and would take them some effort to connect with previous physics knowledge.

A 12 kg heavy child fell down from a window at 52nd-floor which is 171.6-meter high. The evil Dr. Ock Teaser (90kg) at the bottom of the building sees the kid falling off the window and starts climbing upwards with his six metal claws to catch the baby. Each claw can execute 200N force to lift him. Luckily, Spiderman (65kg) is at the top of the skyscraper which is 198m high. With his hairs gluing on the top of the building, he is flying down to save the baby.

To save the baby, at which velocity must Spiderman jump down from the top?

Figure 1.   Example of the condition "Collaboration with hints"

Figure 1 illustrates one of the problems. It is a five-step problem and is used as an example to demonstrate the condition "Collaboration with hints".

Students were required to work according to a script on the five episodes. The hints that go with each episode were on cards and numbered sequentially from 1 to 5. The hints consisted of a text that described the main topics in an episode and a diagram that depicted the problem situation. As hints progressed the diagram became more and more detailed. We expected this external representation to help maintain the focus in discussion and we expected the details to help students solve the problems (Jonassen, Peck, & Wilson, 1999). The hints were put upside down in front of the two students. There are no unbending rules using the hints, but the students first have to think of the answers to fill in on the log sheet and discuss them with each other before using the hints.

Problem survey (read, analyze).   Students are required to verbalize the problems to identify the known and unknown information of the problem, and determine a general approach that is appropriate to this situation, such as what kind of concepts and principles will be useful in solving this problem. The result of their discussion can be a rough picture showing the objects, their motion, and their direction.

Active knowledge (explore).   Students are asked to translate their sketch into a scientific description with a diagram. In the diagram they define variables to calculate desired quantities. They write down the formula that may help to solve the problem. The hints may be used only after the discussion.
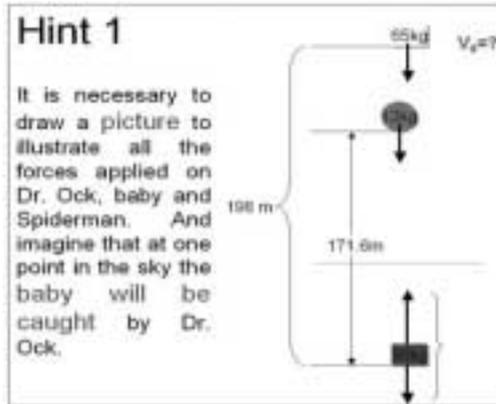
Figure 2.   Hint 1

Make a plan (plan).   After making a scientific description, students are asked to make a solution plan individually. This plan should involve the steps in the equations and rough estimates of the outcome. Then they are asked to put their plans together to compare. It is not necessary that there must be consent or one must follow the other's plan. Comparison of the solution plan simply makes students aware that more than one solution is possible. They may use the hint to check whether they are on the right track or they may correct their solution plans if necessary.

Carrying out the plan (implement).   Students are asked to translate their own plan into a series of appropriate mathematical actions by substituting the numerical values into a formula and to solve the final equation. It is necessary for them to check regularly whether they are meeting their targets and revise the plan accordingly.
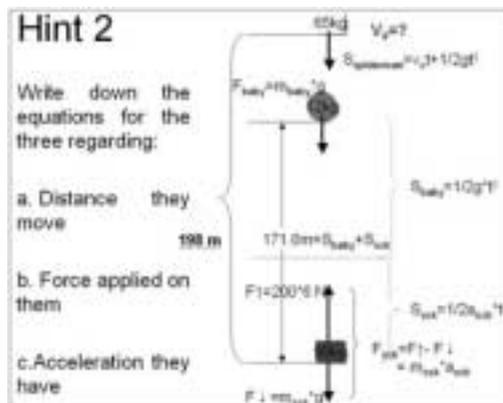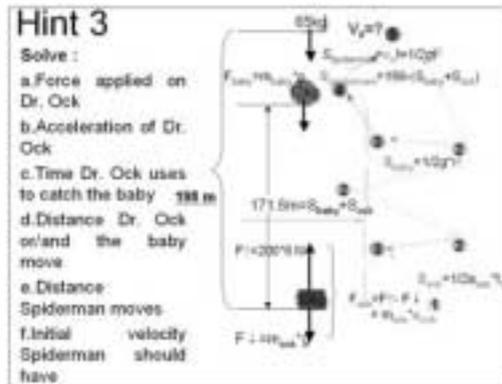

Figure 3.   Hint 2

Figure 4. Hint 3

Control of the answer (verify). Based on their answers, students are encouraged discuss their solutions. When they have got the same answers, they are asked to retell their solving process and check whether they have really arrived at the right solution. If their answers are different, they should determine whose is correct or complete. They are also asked to reflect on what they had learnt for future problems and tasks, and what kind of strategies are more efficient and can be adopted later on.

At the end, students were given a worked out example as the final judge of their solution. The students wrote their information about the five episodes in a log sheet (see later) and especially elaborate upon the verification of their answers.

Assessment instruments

Participants completed both a pre-test and a post-test. The pre-test consisted of two problems about forces and the post-test had two similar problems. The test
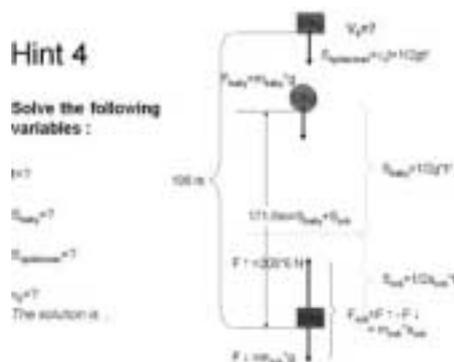

Figure 5. Hint 4

Figure 6.   Hint 5

problems have much in common with the problems in the program. The test prob-
lems are contextual and are about the topic of forces. However, the test problems are
not as complicated as the problems in the program and need only three steps to
calculate. The contexts in the test problems are different form those in the program
and relatively new to the students. One of the problems of the post-test is stated in
Figure 8.

   Both the pre-test and post-test were given in open-question format. Responses on
each episode were given from 0 points (no information) to 5 points (correct and
detailed information). The students were required to give information about four
episodes: analyze, explore, plan, and implement. In total 20 points for each question
could be gained. Since students in both pre-test and post-test were asked to solve the
problems individually, the final stage—verifying the solution—was not taken into
account.

Figure 7.   Worked out example

Robin Hood (mass=60 kg) is escaping from a dangerous castle. With one hand he is gripping the rope that holds up a chandelier (mass=240 kg). When he cuts the rope where it is tied to the floor, the chandelier will fall, and he will be pulled up toward a balcony which is 20 meters above. The nearest enemy will kill him in 3 seconds. Ignore the friction between the rope and the beams over which it slides, and find whether it is possible for Robin Hood to escape safely.

Figure 8.   One of the problems in the post-test

Procedure

Introduction.   Prior to the pre-test we used one lesson for an introductory training. First, students of all conditions were shown a videotape. In the videotape, two students solved a physics problem concerning forces while discussing their ideas following the episodes of problem-solving. We showed this video to make sure that all students understood the idea of working with the log sheets. Thereafter, students in condition CL+H were given instruction with a sample problem in how to collaborate in each episode using the hints. The students in condition CL were given instruction with the sample problem in how to collaborate in each episode. In both collaborative conditions students were asked to solve a problem by thinking aloud and following the episodes on their log sheet. The students in I+H were given instruction in how to use the hints with the sample problem. Students in condition I only did the sample problem. All students filled in a log sheet and received the sample answer so that they could verify their solution.

Pre-test.   Subsequently, all students took a 1-hour pre-test and were asked to finish two physics problems individually and without any hints at hand.

Training.   The students were grouped as aforementioned in the experiment. Within each class, students were divided randomly into four groups. The conditions CL+H and CL consisted of 26 students (11 boys, 15 girls) and 25 students (11 boys, 14 girls), respectively. In the two collaborative learning groups, students were randomly assigned to their peer learner. The conditions I+H and I consisted of 23 students (eight boys, 15 girls) and 25 students (16 boys, nine girls), respectively. All students were required to spend six lessons of 50 min working on six problems about forces and movement. Students had to apply knowledge of Newton's laws that was taught the year before. Students in all four conditions were given log sheets on which the

Starting time:	Problem number .....
1. Read & Analyze *Make scheme or diagram*	Answer: *Use of hint? Y/ N**
2. Active Knowledge *The equations or theorems you need*	Answer: *Use of hint? Y/ N**
3. Make a Plan *Work it out in steps*	Answer: *Use of hint? Y/ N**
4. Carry out the Plan *Your calculations*	Answer: *Use of hint? Y/ N**
5. Verify the answer *Did you give a complete and correct answer?*	Answer: *Use of hint? Y/ N**
Ending time:	Comments on the process:

* *Only for conditions with hints*

Figure 9.   Log sheet (shortened version)

five episodes of Schoenfeld's problem-solving strategy were listed (Figure 9). They filled in the sheets for each problem.

Log sheet.   In the collaborative conditions (CL+H and CL), students had to discuss their individual answers with their peer learner and write down the results on the log sheet. After calculating the answer, students in the two collaborative groups were required to verify and compare their answers. They had to retell their solutions to their peer learner if the answers were the same. If different, they were encouraged to discuss and find out from which part their solving process diverged. After discussion, students had to write down some comments on their peer learner's solving process, and to evaluate their peer learning as effective or not. In groups CL+H and CL students filled in the log sheets with the fifth episode to exchange their learning experiences. In the other conditions (I+H and I), students filled in the log sheets on their own decision. In condition I+H the student working individually were provided with five hints. The only difference with the students in condition CL+H was that the fifth hint (verify) is merely to remind the student to reflect on the answer by himself or herself.

   From the log sheets the researchers gathered information about the problem-solving process in the four conditions: how many problems were solved correctly, which

information students gave about the episodes of a problem, and the time of start and completion of a problem.

Videotapes and observations.   More qualitative process information was gathered by making videotapes during the program of two pairs of students in condition CL+H and in condition CL. The students' conversations were videotaped and transcribed. Two students in condition I+H and condition I were asked to verbalize their problem-solving activities while they were videotaped. Not only video registrations were made but also naturalistic observations of students at work. During the six lessons, one of the researchers observed the students in the four conditions and made field notes of the nature of their learning activities.

Post-test.   Students were asked to take the post-test individually. The time set for it was 60 min.

Interview.   An interview was held by the researchers. Four students from each group were selected and were asked how they solved the physics problem and how they had experienced working with the log sheets, the hints, or structured collaboration.

Results

Implementation of the Treatments

Implementation of condition CL+H (collaborate on problem-solving with the help of hints). Students in this group spent more time on problem-solving than their counterparts in other groups. From our observations during the experiment we learnt that the students needed time to elaborate on the episodes. All of the students in this group were engaged in problem-solving until the end of each lesson. The log sheets showed that 85% of the students reached correct and complete answers with at least five problems. Their data of most students were detailed. From the observations it appeared that the students in this condition could manage their discussion effectively. For those who liked to start hastily, their peer learners often made them deliberate on planning and working out the solution. When students found it hard to agree with each other, they ceased their discussion timely and resorted to the hints as just-in-time instruction. This was evidenced by the dialogs in the dyads. We give an example of the Spiderman problem from the video recording:

> Kaijie Liao: There is a 1200 N force applied on Dr. Ock. So his acceleration should be a = 1200 N/90 Kg. Based on that we can calculate the distance he moves.
>
> Lily Dai: I don't quite agree with you. Yes, we should first focus on Dr. Ock, but there is not only one force applied on him.
>
> Kaijie Liao: What do you mean exactly? There is definitely only one force applied on him.

Lily Dai:	How about his own gravity, 90Kg?
Kaijie Liao:	Yes, he has. But this has no relationship with what we are going to solve.
Lily Dai:	But this force is exactly in opposite direction to the force the claws have.
Kaijie Liao:	No. We do not need to take it into account. I think we should use 1200N as the only force applied on Dr. Ock….
Lily Dai:	So, let's read the hints and find out if they can help us.
[They chose Hint 2 for help, and read for a while]	
Kaijie Liao:	Ok, I see there were two opposite forces applied on Dr. Ock, and we can only use the net force to calculate the acceleration, and it should be 1200 N-mock$\star$g … Yes, I see it now, it is the gravity. You are right.

Implementation in condition CL (collaborate on problem-solving without hints). Most of the students finished the six problems in time and had a few minutes to spare in each of the six lessons. Only 64% of students answered at least five problems correctly. However, most of the students could illustrate physical variables as required in a diagram or scheme. The log sheets show that most of the students could find correct equations for the problems but about one-third of the students used the equations incorrectly while others planned it improperly. The log sheets of the students mirrored that some had tried incorrect solutions to get the answers. The observations and videotapes showed that the students interacted actively. However, it is worth noting that in this condition collaboration could easily change into one-sided interaction, which can be evidenced by the following videotaped dialog between students:

Zhenghong Wu:	The distance Dr. Ock moves should be S = 1/2g $\star$ t^2. So we can …
Shan Jin:	I wonder whether this is right, S = 1/2g $\star$ t^2. I think, maybe the acceleration of Dr.Ock is not the constant g, but something else.
Zhenghong Wu:	What is it exactly? Of course, it should be the constant.
Shan Jin:	But there are two forces executed on Dr.Ock, not only his own gravity.
Zhenghong Wu:	Yes, that's right. But these two forces are in the same direction, so we do not need to take them into account.
Shan Jin:	Are you sure?
Zhenghong Wu:	Yes, believe me. I am totally sure.
Shan Jin:	Okay, okay. I follow what you've said. Anyway, you did better in physics than I.

Implementation in condition I+H (solve problems individually with the help of hints).
Most students in this condition finished their problems well before the lesson time ended. The majority (78%) of the students solved at least five problems correctly, and the episodes were well described. The other students especially failed in executing the solution plan the hints indicated. The log sheets show that in the first two episodes most of the students could draw up a diagram and find a correct solution plan. The students in this group took the hints frequently. The log sheets show the students often improved their solutions after looking into the hints. We asked some students to think aloud and solve a problem. Here is an example we video-taped:

Junhua Zhang:	Three variables, Spiderman, baby and Dr. Ock … which should be solved firstly? Spiderman?

[He thought for a while]

Junhua Zhang:	Yes, I think so, because we need to know his distance and then the falling speed. En…but the information here is not enough to solve the distance. Huh …

[He picked up Hint 3 for help]

Junhua Zhang:	From the hint, I should first solve how many seconds Dr. Ock needs to catch the baby. So I should first begin with Dr. Ock, not Spiderman.

[Then he began to calculate the variable for Dr. Ock. But soon he encountered another problem]

Junhua Zhang:	But what comes next?

[He thought it over, and picked up the same hint once again. He read for a while]

Junhua Zhang:	Oh, I see, the time is important. First calculate the force applied on Dr. Ock, and then how many seconds he needs to seize the baby. And based on this calculated time, we can infer the distance baby moves, and … Ok, I see, after that, how long Spiderman will move can be drawn, and then that will be easy to know the initial speed of Spiderman. It looks like a reverse method of mine.

[Then he went on calculating without taking Hint 3 any more]

From our observations we conclude that the think-aloud protocol of Junhua Zhang is typical of students in this group. They spent much time reading Hint 2 recalling the equations they need and Hint 3 about making a plan. However, very few of them did check their answer as required in the last episode named "Verify".

Implementation in condition I (students solve problems individually without hints).   Most students of this group needed all of the lesson time. Many students in this group did not fill in their log sheets completely. Only 52% of the students finished the problems in due time and gave correct answers. The other students could not finish answering the problems as required. Most of these students experienced hindrances at the beginning episodes. They understood the problems and made a scheme or a diagram but failed to recall or choose the right equations and theorems in order to make a solution plan. Some of these students therefore used inappropriate or incorrectly remembered equations. The use of time on the episodes differed greatly among the students. Some used only 5 min on the first episodes speculating for correct equations, and once they had decided on a solution plan they would follow it up even if it led to totally incorrect answers. Others spent a long time on one episode and could not finish their solution in time.

Learning Outcome

In Table 1 the means of the students of the four conditions are shown. The students were randomly assigned to the conditions, so we would not expect a significant difference between students of the four conditions on their knowledge of solving physics problems about forces and movement in the pre-test.

Table 1. Pre-test and post-test means with standard deviations for four conditions

	Mean pre-test (scale 0–40)	*SD*	Mean post-test (scale 0–40)	*SD*
Collaboration with hints	8.12	7.40	26.88	8.10
Collaboration	9.80	8.45	26.52	10.63
Individual learning with hints	9.39	8.01	27.57	14.84
Individual learning	8.08	7.82	18.92	13.56

To ensure that the students of the four conditions do not differ on the pre-test, an analysis of variance (ANOVA) was conducted with condition (four categories) as the independent variable and pre-test score as the dependent variable. The ANOVA test for difference between the mean scores of the students in the four conditions yielded a value ($F = 0.31$; $p = 0.82$). This results show there was no significant difference among the students in the four conditions on the pre-test.

To examine the differences of the treatment effect, an analysis of covariance (ANCOVA) was conducted. The difference in experimental treatment (four conditions) is the independent variable, the pre-test is the covariate, and the post-test score is the dependent variable. We use a covariate to control for small differences between the students of the four conditions that may confound the effect of the experimental condition.

The post-test means of the students of the four conditions are presented in Table 1. Before testing the effect of the factor "condition" we had to make sure relatively high-scoring or low-scoring students on the pre-test did not profit more on the post-test in any of the four conditions. We checked for an interaction effect of "pre-test * condition". The ANCOVA showed that apart from the main effect of the factors "experimental condition" and "pre-test" there was no such interaction effect ($F = 0.18$; $p = .91$). The main effect of the experimental condition was significant ($F = 2.7$; $p = .048$).

As the differences in means between the four groups in Table 1 indicate, a contrast analysis showed only a significant difference between conditions CL+H, CL, and I+H, on the one hand, and condition I, on the other (contrast estimate = – 3.9; $p = .005$).

Research question I: does collaborative learning without hints improve students' problem-solving learning more than individual work without hints?. This question is about the hypothesis that collaborative problem-solving as such, and without extra help, leads to better learning outcome than individual problem-solving. The mean and standard deviation of post-test scores for those learning collaboratively are 26.52 (10.63) and their counterpart in individual learning group scored 18.92 (13.56). A significant difference between these two groups was found in the contrast analysis.

From the interviews with the students from the two "collaborative learning" groups it appeared that they had enjoyed the program, although they had never

experienced collaborating learning in scientific disciplines yet. Prior to that, collaborative learning was only used in Chinese writing courses to pool possible viewpoints on a certain topic. From their peer learner, they have learnt that there are various solutions to one problem. Collaboration encouraged a free flow of ideas, and deepened their understanding of the problem since they had to spend more time on analyzing the problem than they probably would without a peer. Students found that they could remember the formulae and equations much better, particularly when the equations were discussed with their peer learner.

Research question 2: does individual learning guided by hints improve students' problem-solving learning more than individual learning without hints?.   This question is about the hypothesis that individual learning with the use of hints leads to better learning outcome than individual problem-solving without hints. The mean and standard deviation of the post-test scores for those learning with hints was 27.57 (14.84), much higher than those learning without hints (18.92 [13.56]). A significant difference between students "learning with hints" versus students learning "without hints" was found in the contrast analysis.

   In the interviews, students who studied using hints agreed that Hint 2 (explore) was important for recalling the related equations and theorems. Hint 3 (plan) and Hint 4 (implement the plan) were of particular importance to help with their solving efforts and to avoid being on the wrong way. Psychologically, they felt much better when they were aware of hints at hand. They did not use Hint 5 (verify) very much.

Research question 3: does collaborative learning guided by hints improve students' problem-solving learning more than collaborative learning without hints?.   This question is about our main hypothesis that collaborative problem-solving with hints leads to better learning outcome than collaborative problem-solving without hints. From prior research we knew that scripted collaboration has better learning effects, but we had no indication that scripting collaboration with hints could improve learning. The post-test scores of those learning collaboratively with hints are 26.88 (8.10), only slightly higher than those learning collaboratively without hints (26.52 [10.63]). The contrast analysis revealed that the difference between these two groups was not significant. So, from the mean post-test scores it cannot be concluded that collaboration guided by hints excelled collaborative learning without hints.

Discussion

We structured a collaborative learning environment by converting Schoenfeld's problem-solving strategy into a sequence of activities students had to do. We wanted students to follow a script and put in hints with each episode in order to provide scaffolding that could cause knowledge convergence between students (Weinberger et al., 2001). Our research shows a relationship between explaining and discussing a problem between students and their growth in problem-solving abilities. As expected

in our Hypotheses 1 and 2, the post-test scores revealed that both collaborative learning with and without hints and individual learning with hints improve students' learning outcomes. Very little is known about how to design effective collaboration environment for solving physics problems more effectively than structured individual learning environments (Nelson, 1999). Structuring of the collaborative process is needed, but to what extent? Can the structuring of collaborative learning be of the same kind as structuring of individual learning? The outcome of our research suggests this is not the case. Individual learning can be improved by structured hints that provide detailed instruction of what to do in episodes of problem-solving. We saw that in this study just as in previous research (e.g., Pol et al., 2005). In individual learning the hints function as an expert to whom the student can resort. However, in collaborative settings the expert in the background may not be effective for stimulating discussion between peers. We think the use of such an expert does not improve elaborative interaction and knowledge convergence between peers. We will discuss this further and try to explain why collaboration with hints had no extra effect.

Nature of the Hints

Hints designed for this study were very detailed, which left little room for argumentation between students after the hints were taken. The hints had a final saying in the discussion and that is probably not good for independent thinking. The hints we used in this study can be characterized as "just-in-time-instruction" and not as "meta-cognitive suggestions to solve a problem". Just-in-time instruction will be effective for students working alone who do not know how to proceed. For students working in a group we probably better use suggestions that stimulate them to form their own strategies. That may be one of the reasons why we did not find an extra effect for collaboration with hints compared with collaboration without hints.

Nature of the Interactions

In the condition CL, a number of disagreements had to remain. For instance, once students could not agree with each other, they were inclined to end their discussion and frequently with such words as "Ok, I am not good at physics, so I follow what you've said." In the CL+H condition students kept a dialog going and referred to the hints if they did not agree or did not know how to proceed. In CL+H, most of the students did verify and discuss their solutions. This was less so in the CL condition and still less in the I+H condition. So, it seems that collaboration with hints has at least some effect on students' problem-solving behavior. Although these differences in problem-solving behavior did not result in higher post-test results it does show that condition CL+H had some of its intended results. In order to investigate the effectiveness of the interactions between the collaborating students, the dialogs of the students can be analyzed. Argumentation and reasoning next to questions and proposals will be important components of effective communications between

students. Dialogs with these components will structure the solution approach and will stimulate the growth in problem-solving abilities.

Allocated Time

In the interview, students in the collaborative with hints condition put forward that they needed more time to relate the information from the hints to the discussions with their peer learner. Within the limited experimental period, they could not develop a routine in combining these two sources of information.

Group Formation

Students in the interview wished to find their peer learner by themselves. In the two collaboration groups, we have observed that each pair spent a certain amount of time in getting familiar with each other.

Implications

Although our research did not bring a clear indication of how to structure collaborative learning more effectively, it showed the value of hints when learning individually and the value of collaboration as compared with learning individually. We feel there are some important points to be made out of our research for designing collaborative environments, especially when using CSCL as we plan to do.

First of all, the verbal dialogs of students have to be traced and explored in a future study. In a computer environment conversations between students can be logged, as well as hints used and drawings made. With the help of these data we may analyze the communication functions students use in collaboration conditions with and without hints, and study effective interaction patterns for the development of problem-solving abilities (Erkens et al., 2003).

Secondly, the nature of the hints should be changed in the collaboration condition. The hints should not be used as an expert students can refer to as soon as they do not know how to proceed, but provoke further discussion with suggestions for drawing a schema, making a diagram, or making a plan with equations. The hints should provide diagrams with less details and suggestions about how to proceed. We expect this type of hints to stimulate discussion among the students (Suthers, 2001). In CSCL one may offer students a computer screen with a common area where students can drag and drop a diagram and make alterations or add extra information (Erkens et al., 2003; Van Someren, Reiman, Boshuizen, & De Jong, 1998). Especially in the collaborative condition, hints should induce students to tap their own knowledge reservoirs and to share what they know. Students should be able to follow on screen what their peer is doing and communicate with each other in text and in audio.

Thirdly, the collaborative script should be tailored to the student's level. Students should be allowed to work for some time individually first and than put forward their

ideas on screen. The episodes should be used as points for idea-generating and discussion, to make sure all necessary ingredients are there to solve a problem systematically. During their mutual elaborations students can exchange the ideas they have worked out for themselves. Students should be allowed to use the suggestions in the hints of the program that can help them to confirm they are on the right way or put them on the right track. Students have to be trained in order to work smoothly with this script. In the course of the program students should be allowed to develop a kind of working relationship that suits them best. They may deviate from the script as long as they elaborate and exchange ideas (Fischer & Mandl, 2002).

Furthermore, the time of this experiment (six lessons) was probably too short for the students to develop a personal or mutual strategic approach to the problems. The period was also too short to develop collaborative routines. In Table 1 we can see that on average the students in the experimental conditions could only reach about 70% (27 out of 40 points) of the scale on the post-test. A series of lessons with problem-solving opportunities is needed. Therefore, it is intended to extend the program.

Finally, a common interest and mutual understanding between peer learners are crucial to effective collaboration. It is advised to create groups taking into account not only the difference in prior knowledge of the students but also the preferences of students for a peer learner (Johnson & Johnson, 2000).

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