Computer based instructional support during physics problem solving

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Problem-solving plays a major role in physics education. Secondary school students need problem-solving skills to answer questions in tests and final exams, while some students who go on to higher education will be required to solve problems in physics or related subjects. This is a report on a study investigating how students attending pre-university education (fourth year) can be helped to solve physics problems in the topic of forces.

Students need different kinds of knowledge and skills in order to be able to solve problems. Firstly, there is knowledge of facts and concepts about a particular subject, which we call declarative knowledge. Secondly, students need to know how to apply this knowledge of facts and concepts, or procedural knowledge. Examples include applying a formula, as well as more general procedures such as numeracy skills. Thirdly, knowledge of more general strategies is needed to solve problems. Students must analyse a problem, take the time to organize their own background knowledge and devise a plan to solve the problem. They also need to reflect on the process during and after problem-solving (meta-cognition). This is called strategic knowledge.

The focus within Dutch school practice is primarily on developing declarative and procedural knowledge, with much less emphasis on teaching strategic knowledge. In fact, strategic knowledge is only highlighted during preparation for the final exams. This raises the question of how student strategic knowledge can be improved. The literature shows the conditions under which this can be done:

- students should play an active role in problem-solving
- students should be given an opportunity to develop their own problem-solving strategies
- students should solve many problems in many different learning situations within a specific domain
- during problem-solving, the problem-solving process itself and reflection on it should be emphasized.

Offering computer support during problem-solving within regular education is one way to meet the above criteria. Designing computer support
entails making various decisions. The first is whether support should be given before, during or after problem-solving. Considerable experience has been built up in offering instructions before students tackle problems, but this type of support primarily improves declarative and procedural knowledge. The research literature shows that the most effective way to promote the development of strategic knowledge is to offer help during and immediately after problem-solving. This is the form of support selected for the experiments in this study.

A second decision concerns whether support should be computer-driven or student-driven. Because students require opportunities to develop their own strategic knowledge, we opted to allow students to decide when and which kind of support they needed.

The third decision relates to the type of task on which students work and the variation in the model answers presented by the computer. For this study we opted for tasks involving different solution routes but a single correct answer. If a learning environment supports only one way to solve a problem, the assumption is that this is the best way. By supporting several solutions and outcomes for a particular problem, this suggests that there is no single best way and that students themselves should decide which best suits them. This is expected to promote the development of strategic knowledge. To ensure that students did not lose their way while solving problems, the program presented students with a range of options within a fixed structure.

This thesis describes a study into the effect of the computer program *Physhint*, a learning environment based on the principle of student-driven support, provided at the time students need it. The above criteria for developing strategic knowledge were considered in the design of the learning environment. These were an active student role, learning support in the form of several ways to solve the problem, diverse task contexts and an emphasis on reflecting on the problem-solving process.

The study was conducted to answer the following two research questions arising from the literature review:

1. *Does student use of a computer program during and after the solving of physics problems in school practice improve their strategic knowledge?*
2. *How does such a computer program improve the development of students’ strategic knowledge?*
Students can use *Physhint* during regular lessons to solve physics problems. The problems presented in the chapters on forces in the physics textbook can also be found in the computer program. If students opt to work out a problem in the program, this will appear on the left of the screen. A menu with keywords of possible hints is shown on the right of the screen, together with an opportunity to enter and to check answers.

The menu containing the keywords of hints is arranged in accordance with Schoenfeld’s episodes for problem-solving. According to Schoenfeld, experts solve problems by first of all analysing the problem thoroughly, seeking the tools required and then making a plan and carrying it out. The problem-solving process is completed with a check and an evaluation of the solution. Students do not need to follow these steps in this exact sequence in order to solve a problem correctly, but they do need to give sufficient attention to all episodes. According to Schoenfeld, novice problem solvers experience particular difficulty finding solutions because they do not spend enough time analysing the problem.

The computer program contains hints for the different problem-solving episodes. The survey heading offers hints on *analysing* a problem, for example drawing a diagram of the problem, or working out an example with numbers. The *tools* heading presents clues for supplementary declarative or procedural instructions needed to solve the problem. If students are still unable to find a solution, they can look under *plan* for one or more parts of the model answer and then proceed. Once the problem-solving process is completed, students are shown a second menu from which to select more model answers with which to evaluate their solutions.

The program effects were investigated in two experiments in which groups of students using the program were compared with a control group (solving the same set of problems) that used a physics textbook containing model answers. In the first experiment, the experimental group used the program that offered hints during problem-solving and model answers after problem-solving (experimental group with hints: \( n = 11 \); control group: \( n = 26 \)). The second experiment was an expansion of the first and included a second experimental group that used the computer program offering model answers after problem-solving but no hints.
during problem-solving (group with hints: n = 18; group without hints: n = 18; control group: n = 23).

For the first experiment, the program was implemented in a secondary school in the northern Netherlands, and for the second, in four secondary schools across the Netherlands that had achieved average final exam results. The participants in both experiments were 15–16 year olds, fourth-year pre-university secondary education students who were supervised by experienced teachers with a grade one teaching qualification.

During the experiments the computer recorded data (use of hints, solving problems, time spent on problem-solving) on use of the program by students in the experimental groups. Comparable data was gathered for the control group by asking students to log it themselves. This information was then checked by the teachers. In addition, students were required to sit four tests: a pre and post-test that tested declarative and procedural knowledge, and a pre and post-test that tested strategic knowledge.

A comparison of the pre and post-tests taken during the experiments showed that students in the experimental groups who used the computer program developed better strategic knowledge than the control group. The first experiment showed that students using the full version of the program with hints while solving problems and model answers after solving problems performed better than the control group which used the textbook with model answers. The second experiment showed that providing hints during problem-solving is more beneficial than simply offering model answers after problem-solving. This experiment also showed that the group using the computer program with only model answers following problem-solving scored better on the strategic knowledge test than the control group with the textbook containing model answers.

In both experiments, use of the program by students in the experimental groups was analysed for possible clues about effective use. The results showed that students in the experimental groups who used the program did not spend more time on problem-solving. However, they did solve more problems correctly. In other words, they had more experience in correctly solving problems themselves.

The study also investigated whether students in the experimental group began making more systematic use of the program’s hints and model answers. Systematic use of hints means following Schoenfeld’s episodes. In other words,
first consulting hints for the survey episode, then for tools, followed by plan, but not in the reverse sequence. Systematic use of model answers entails consulting a model answer, even if the problem has been solved correctly. Some students in the experimental groups showed an increased systematic use of model answers. These students also scored significantly higher on the strategic knowledge post-test than the group that did not increase its systematic use of hints.

We may conclude that both the full version of the program and the version containing only model answers had a positive effect on developing students’ strategic knowledge. These students showing an improvement in the systematic use of hints while using the program, developed their strategic knowledge significantly better than students who did not do so.

This study therefore demonstrated that indirect computer-supported instruction can promote the strategic knowledge of students. The help and feedback offered need to be available immediately and on demand as this gives students an opportunity to develop their own problem-solving strategies. Reflection on the problem-solving process warrants more attention. This can be achieved by having students ask questions about the problem-solving process, but also by discussing different problem-solving options. A combination of making help available during the problem-solving process and providing model answers afterwards can boost the students’ strategic knowledge, thereby helping them to become more proficient at solving physics problems.

The conclusions of the study are limited in several respects. The study used problems that required a single clear answer. Also, the experiment involved the topic of forces within the subject of physics. Further research could be conducted into the program’s effect within other topics and subject areas.

A further limitation is the relatively small number of students taking part in the experiments. Although the study was able to confirm most of the expectations, others were not confirmed. A larger-scale follow-up study could perhaps demonstrate the stability of the effects found. Such a study could be expanded to include a more in-depth analysis within the experimental groups as to how students used the program, whether they viewed it as useful and whether the use
of hints boosted their self-efficacy. This thesis did not pay any attention to these sociocognitive aspects of learning to solve problems.

In addition to the implications for future research, this study has potential implications for teaching. The development of strategic knowledge is important for students because the national examination requires strategic knowledge for the successful solving of problems. Possessing strategic knowledge is also a factor in success in tertiary education. For these reasons, teaching strategic knowledge deserves a greater emphasis in secondary education than it has at present.

The development of strategic knowledge can be encouraged by setting several criteria for the type of problems that students are asked to solve. For example, this study has shown that strategic knowledge can be improved by practising physics knowledge in different situations. It is important that the problems capture students’ interest by being linked to contexts that are relevant to the students. In addition, problems should be set at the right level of difficulty. Students must work hard to solve them, but should nevertheless succeed with the aid of systematic hints. In this way students acquire positive learning experiences in the use of strategic knowledge and should therefore become more self-confident. In practice, this often means that problems can be more difficult and more open than is currently the case.