CHAPTER EIGHT

Conclusions and discussion

8.1 Conclusions

8.1.1 Introduction
Solving problems is an important activity in modern physics education. To do so, students need to possess domain knowledge (declarative knowledge) and know how to use this specific knowledge in standard procedures (procedural knowledge). Most importantly, students not only need to know how to apply science concepts and formulae to standard textbook problems, they also need the skill to apply this knowledge to new problem situations (strategic knowledge). Secondary school education emphasizes the development of declarative and procedural knowledge, while the application of strategic knowledge to novel problems plays no essential role in school practice. In the Netherlands, students are not trained to solve novel problems until preparing for their final exams. These problems are derived from examinations from previous years, which students learn to solve. Most of the time the problems are practised in groups and are categorized according to the underlying declarative and procedural knowledge, but with different contexts.

The literature has shown that the development of strategic knowledge can be influenced in different ways (De Corte, 2004; Mayer, 2008):
- by activating learners
- by giving learners room to develop their own solution strategies
- by practising a large variety of problem situations within a specific domain, and
- by emphasizing the explication and reflection on the learners’ way of solving problems.
While some of these factors have been shown to be effective, most still need more empirical support (Mayer, 2008). And yet others give rise to a dilemma. For example, students need the opportunity to work out problems on their own in order to learn from their own successes and failures in finding solutions, but they
also need guidance that gives them positive experiences which can increase their self-efficacy.

Digital support can be offered individually and can give learners room to develop their own problem-solving strategies. It can also provide students with hints on the way to solve a problem. Support can be given before, during or after problem-solving. The literature indicates that instruction is most effective when available at the moment the learner needs it (Mayer, 2008). This just-in-time instructional support can be made available according to rules determined by the computer (this is called direct instruction or computer-driven support) or the demands of the student (this is called indirect instruction or student-driven support). The first type of support is more effective for beginners in the problem solving process; the second seems to be more fruitful for learners at a more advanced stage of learning to solve problems (Clark & Mayer, 2008).

8.1.2 Overall effect of the Physhint program

This thesis describes the research into the effect of the Physhint computer program, which is based on the principles of just-in-time and student-driven support. Physhint is a digital support system, used in this study by secondary school students working in the domain of vectors and forces. The program offers students problems from this domain and supports them with hints during problem-solving and model answers afterwards. The hints are structured according to a problem-solving framework with problem-solving episodes. The structure is meant to improve the strategic knowledge of program users. There are a few studies on how effective problem-solving programs influence student behaviour (e.g. Schoenfeld, 1992; Harskamp & Suhre, 2006). These studies have helped with the design of Physhint. By incorporating the program into the school curriculum, we attempted to improve strategic knowledge but also to take into account the declarative and procedural knowledge taught at school. The first question this research wished to answer is:

1. Will the use of Physhint in school practice improve students’ strategic knowledge? (Chapters 4 and 6)
The main purpose of this study was to find out if Physhint leads to more strategic knowledge than working in a traditional way with a textbook and model answers. The argument for and characteristics of a computer program were presented in Chapters 1 and 2. The program was expected to effectively support the development of strategic knowledge during the solving of physics problems. Based on findings from the research literature summarized in the first two chapters, the Physhint program was developed.

The project revealed that the groups involved in the experimental condition showed greater improvement in the strategic knowledge post-test (problem-solving post-test) than a control group. Teaching students with the program proved to be more effective in developing strategic knowledge than teaching with the textbook. The experimental groups did not score significantly higher on the declarative and procedural knowledge post-test (knowledge post-test), which means that the significant increase in the scores in the problem-solving post-test of students in the experimental groups can be attributed to an improvement in their strategic knowledge.

Clark and Mayer (2008) point out that allotted time to practise always plays an important role in learning. They state that it is often not the special type of training but the amount of practice that explains the effect. Therefore we checked the time spent by all students on solving problems. The time spent on the project and the number of problems done by the different groups of students were not significantly different. However, students who used the program solved more tasks correctly than students in the control group who used their textbook. This indicates that it is not the time spent on problem-solving, but the effect of the support provided by the program that made them better problem solvers. In the experimental groups, we found positive partial correlations between the number of tasks solved correctly during the project and the results of the problem-solving post-test. This was not the case in the control group. The results thus indicate an overall increase in the effectiveness of practice with the program: the more tasks that are finished correctly using the computer program, the better the problem-solving skills of the students.

We then investigated which part of the program helped students to improve strategic knowledge. Users of the program with hints and model answers showed a significant improvement in strategic knowledge compared with those who only
had model answers available. Therefore it may be concluded that students supported indirectly by hints during problem-solving and worked examples afterwards improve their problem-solving skills more than students who only have model answers available after problem-solving. In this group we also found a relationship between the number of hints and model answers used and the number of tasks answered correctly. The group with only model answers available showed no significant correlation between the use of model answers and the number of program tasks answered correctly. From this evidence it may be concluded that providing model answers after the problem-solving process is only effective if they are part of a total program of help available during and after that process.

8.1.3 Effects of the use of components of the program

The basic assumptions of the Physhint program relate to Schoenfeld’s work (1992) on episodes in the problem-solving process and to his examples of asking students questions about what they do while problem-solving. Schoenfeld did not teach problem-solving directly by letting students follow episodes step by step as a standard procedure. Instead, he asked them what they were doing, what they already knew about a problem, which step they thought they would take next and to reflect if they arrived at a solution. The episodes were used as ‘signposts’ in Physhint. Students could consult these episodes, thus helping them to guide their actions. When students worked out a problem, they could consult a special help section where hints were arranged according to episodes in problem-solving. It was expected that Physhint might influence different aspects of the learning of problem-solving. Improvements were expected through the way students use Schoenfeld’s framework and the hints that go with the episodes of the framework. For example, students might show a more systematic use of the hints while using the program. If students used the hints in a more systematic order, this might indicate a more structured approach to solving problems and might improve their strategic knowledge. The second question this research wanted to answer was therefore:

2. In what way does Physhint influence the development of strategic knowledge during students’ problem-solving practice? (Chapters 5 and 7)
Another purpose of the research was to find relationships between the ways students used hints and model answers and the improvement in their strategic knowledge. I assumed different possible ways in which students used the program and how these were related to the improvement in their problem-solving skills:

- an increased systematic use of the hints in the program
- and/or an increased systematic use of the model answers in the program.

The first assumption concerned a *systematic effect of the use of hints*. According to Schoenfeld (1992), students confronted with systematic support that guides them through problem-solving episodes might improve their strategic knowledge. It was expected that students working with *Physhint* – as novice problem-solvers – would not begin using hints in the order that most experts would. Instead, students were expected to choose hints at random, or to start directly with a hint containing a plan. Later, these students might learn to first consult hints which help in surveying and analysing the problem, after which they could consult the necessary resources, find help with a plan and finally check for alternative solutions with model answers.

The second way in which problem-solving could be improved was a *systematic use of model answers*, which means that students consulted model answers even after giving a correct answer. In such a situation the students consulted the model answers for evaluative purposes.

In the experiments described in Chapters 5 and 7, some of the students in the experimental groups showed an increase in the systematic use of hints and model answers in accordance with expectations based on Schoenfeld’s theory. These students used hints systematically during the process of solving problems, and/or consulted model answers after they gave a correct answer. The students showing an increased systematic use of hints achieved better results on the problem-solving post-test than students who did not show such an increase. We found no difference in problem-solving post-test scores between those students who increased their use of model answers compared with the group that did not. These results show that only students who used the hints in an increasingly systematic way scored higher on the problem-solving post-test. This indicates that they learned to solve problems more systematically than other students in the hints-with-model-answer group. The systematic use of hints probably had an
additional effect over and above the total effectiveness of practising problems with the program (the model-answer-only group).

Thus an increased systematic use of the episodes in the program may indicate an improvement in strategic knowledge. However, this relationship overlaps to a certain degree with an increase in the effectiveness of practice. Both a more systematic use of hints and practice caused students to solve more tasks correctly during the project.

8.2 Reflections

This thesis discusses an intervention seeking to improve the solving of physics problems by secondary school (pre-university) students. The conclusions drawn need to be considered within the limits of the problem definition as stated at the beginning, that is, problems with one clear answer, but often with more solution paths to that final answer. This might be considered one limitation with respect to the design of the pre and post-tests, which only include this kind of problem. As a consequence, this thesis only discusses factors that may improve the solving of this kind of problem, and conclusions cannot directly be generalized to strategic knowledge needed to solve ill-structured problems (Shin, Jonassen & McGee, 2003).

A second possible limitation is the choice of the topic of forces. Research in the 1970s and 1980s showed that it is not easy to achieve the transfer of problem-solving abilities from one domain to another. Therefore this thesis only studied the improvement in more general problem-solving abilities within the limits of a single subject (De Corte, 2004; Mayer, 2008). It is not self-evident that the strategic knowledge acquired can be applied in other domains or other contexts (Cognition and Technology Group at Vanderbilt, 1997).

A third possible limitation concerns the size of the experimental groups. This thesis describes two experiments with a relatively small number of participants. In particular, the experiment described in Chapters 4 and 5 has only a small number of participants. However, significant results were reported, which says something about effect size. The experiment as described in Chapters 6 and 7 covers a larger number of students and schools, thus increasing the power of this
experiment. Nevertheless, a new experiment with more students and schools might make the results of the two experiments even more convincing.

A fourth limitation concerns the selection of teachers. The first experiment described in Chapters 4 and 5 involved two teachers from one school, which means the effects we found need to be seen in the light of a single school situation. This issue was partly addressed by the experiment in Chapters 6 and 7, in which five teachers were involved. The teachers were from different parts of the northern and central Netherlands and from different types of schools (both a ‘gymnasium’ and general secondary schools). A second way of addressing the issue of a possible teacher dependency was the use of a research design in which students within classes were assigned to either an experimental or a control condition. This controlled for the factors ‘teacher’ and ‘class the students belong to’ in the experiments. Several measures were taken to ensure that the lessons in the different schools were equivalent. First, teachers were given a concise booklet of teaching instructions. Second, teachers were asked to hand in their lesson plan. Third, teachers were consulted regularly through visits and telephone calls. Finally, the students’ login files during the use of the program were checked for student progress.

A fifth limitation concerns the lack of observations of the problem-solving process the students followed. The experiments show that Physhint seems to be beneficial for its users. Tracing the use of hints and model answers during program use gives an insight into the development of students’ problem-solving abilities during the project. However, the data collected from the log files only shed light on the clicking behaviour of students, and not directly on their problem-solving process and cognitive elaborations. More in-depth qualitative research in which students are asked to think aloud might give a greater understanding of the relationship between the problem-solving processes and the use of hints during the program (see Chapter 2).

The sixth limitation concerns the influence of the task level in the experimental groups versus the level of tasks in the control group on problem-solving abilities. To encourage the use of hints in the program, in the experiment in Chapters 6 and 7 the students in the experimental groups were given the same problems from the textbook, except that some sub-questions were left out in order to make the problems in the computer program harder to solve (see Van Heuvelen,
1991 a, b). But when looking at the number of tasks worked out correctly, we saw that the experimental groups solved more problems correctly than the control group. Furthermore, students in the experimental groups outperformed students in the control group on the problem-solving post-test, thus confirming that offering tasks with fewer sub-questions can positively affect the development of problem-solving abilities.

A last limitation is the difference in media. Students in the experimental group used the computer and students from the control group used the textbook with model answers. The literature supports the idea that a difference in media (computer versus textbook) may cause differences in test scores (Clark, 1994; Woodrow, 1998). Students using a computer might work differently from those working with the textbook. For example, in using the computer program, students filled in their answers, received feedback and were required to try again if their answers were not correct. The students from the control group checked their solutions by comparing their answers with the model answers in the textbook. The fact that the feedback was provided by the computer may have caused a difference between the experimental groups and control group. Another aspect which might play a role is that the work of the students in the experimental groups was logged, making the results visible to the students, which may have motivated them. The question as to which of the possible causes might be responsible for the differences between the experimental group with only model answers available and the control group suggests a need for further research using the program version in which both hints and model answers are left out as a control condition (e.g. the computer is used as a check for the answer to problems).

8.3 Implications for further research

In sum, this research justifies the use of the full version of Physhint in school practice. There is evidence that the program has an effect on learning to solve physics problems and on the development of strategic knowledge. As we observed above, more detailed research could be carried out in order to further confirm and specify the results of the experiments.

Firstly, there is a need for research that can disentangle the different effects of the program: the effectiveness of practice and the effect of the use of hints. The
effects found are probably caused by a combination of factors, but it would be interesting to examine the relative effects of different factors involved in the intervention. Through the analysis of log files, this thesis gives some insights into different aspects influencing the development of strategic knowledge. We found indications of a general increase in the effectiveness of practice with the program, and specifically by offering a combination of hints during and model answers after problem-solving. More research is needed to give more convincing theoretical explanations of how the program influences student problem-solving. It would be interesting to study the problem-solving behaviour of individual students by monitoring them more closely when solving problems using Physhint (e.g. by asking them to think aloud).

A second point for further research is the possible merits of the Physhint program when used by different types of students. This thesis reveals that students who showed an increased systematic use of hints during the program profited more from the program than students who did not show this behaviour. The qualitative research proposed above might also shed light on the use of the program by these different groups of students and thus might suggest ideas on how to best support them. The question would then be whether it is possible to change the support offered by the program in such a way that low-achieving students profit more from the program than do high-achieving students. In Chapter 1 we already stated that poor problem solvers need more structured support, which raises the idea of helping them by means of a version of Physhint which offers hints in a structured and program-controlled way (direct instruction). The program can then select poor problem solvers by means of their incorrect answers to problems.

Thirdly, research with Physhint as described in this thesis was limited to the domain of forces. The transfer of strategic knowledge to other domains cannot be expected unconditionally (Bransford et al., 2000). Therefore, research into the broader application of the strategic knowledge taught through Physhint might shed light on the usability of this knowledge in other domains. Although Physhint may in principle be extended to other areas, especially in physics education, it cannot be implemented unconditionally in other domains. Other domains contain different declarative and procedural knowledge, and strategic knowledge might also play a different role in domains different from the one investigated here. Research into
another version of Physhint for these domains might therefore provide insight into the broader application of the theoretical framework presented here.

Finally, Physhint was evaluated within a relatively short period. Since normally a longer period is expected in order to improve strategic knowledge, it would be useful to evaluate the long-term effects of the program. This could be measured by implementing the instruction as used in Physhint into other physics areas and across a longer period.

8.4 Implications for school practice

In this final section, I will try to extract some implications for the instruction of problem-solving skills in school practice on the basis of the research described here. These implications can be divided into three strands:

- the importance of strategic knowledge in school practice
- the type of problems needed to improve strategic knowledge
- the additional support needed to improve strategic knowledge.

8.4.1 Importance of strategic knowledge

At first sight, only declarative and procedural knowledge play an important role in solving the problems that textbooks offer. However, strategic knowledge is also necessary in solving problems at an early stage, especially if the declarative and procedural knowledge needed to solve the problems has not been learned sufficiently. Once students have a better developed toolbox of strategic knowledge, they are better equipped to solve problems for which they need new declarative and procedural knowledge. The improvement in strategic knowledge thus helps students to learn in a more general way.

Although implicit, strategic knowledge also plays an important role for students in a different way. Students sitting central physics exams at the end of secondary school in the Netherlands have to tackle problems comparable to those used in the strategic knowledge post-tests in this thesis. Improving their strategic knowledge can therefore help them to pass this exam. Strategic knowledge also plays a more important role in tertiary education (Taconis, 1995).

The reason why the teaching of strategic knowledge is given little priority in school practice may be due to the overloaded Dutch curriculum (NiNa, 2006).
Teachers think they have to cover every topic in the curriculum, leaving little time during lessons to improve the learning of strategic knowledge. Teachers wanting their students to show more expert-like problem-solving should practise all types of knowledge needed to solve problems (i.e. not just declarative and procedural but also strategic knowledge). An appeal should therefore be made to curriculum developers to reduce the number of items in the curriculum in order to give teachers room to prioritize the development of skills such as strategic knowledge.

8.4.2 Types of problems and how to use them in class

The types of problem students practise is a crucial factor in developing their strategic knowledge. Such knowledge can be improved by offering interesting problems that engage students. Problems can be made more interesting through the addition of an image depicting the situation and a context that makes the problem more interesting to solve. Let us take the following textbook example, which is not very interesting:

An aeroplane accelerates down a runway at 3.20 m/s\(^2\) for 32.8 s until it finally lifts off the ground. Determine the distance travelled before takeoff.

Figure 8.1 offers an alternative description of this problem which was not used in the project. The problem can be made more interesting through a few alterations. It is essential to place the problem in an interesting context that might make the student curious about the answer.

An aeroplane sits at the beginning of a runway. It accelerates down the runway at 3.20 m/s\(^2\) for 32.8 s until it finally lifts off the ground. The runway is 2 km long.

- How much distance is left on the runway as the aeroplane takes off?
- Do you think this is a safe distance?

Figure 8.1: Alternative problem description of a regular task

In the example above, students can imagine the runway as a long stretch of tarmac needed for the plane take off, and they may become curious about whether
this can be done safely. If the runway is 2000 meters long and the aeroplane takes off after 1720 meters, there is not much runway left in an emergency. With a few changes, standard problems can often be made interesting for students. It is assumed that daily situations or situations that students can easily imagine are particularly suitable for problem-solving, especially when a broader goal is added instead of simply doing calculations (Barab & Plucker, 2002).

A further point to note is that appropriate tasks are ones that provide students with situations that require an appropriate degree of effort to solve. This means that students should put some effort into understanding what the problem is about and finding a solution, but the problem should not be so difficult as to make it impossible to solve. Especially appealing are problems that can be solved in more than one way. In the example, the student can calculate the distance second by second or use an overarching formula. Or a velocity-time diagram can be made of the situation, after which the surface under the graph can be calculated.

In effective problem-solving teaching, the problems should be varied and there should be a focus on the different types of knowledge needed to solve them. For the program, we selected the more open problems from the textbook, although there was always one correct answer. These were called semi-structured problems. Most teachers do not choose these problems very often because they think that students are not able to work out the problems themselves and need too much help.

When considering the improvement in students’ strategic knowledge, it is important to not only look at the type of problem, but also the number of problems effectively worked through by students. As shown in this thesis, an opportunity for problem-solving practice and the number of problems solved correctly have a considerable effect on independent problem-solving (achievement). Although this may seem obvious in teaching, it is not. Especially with the implementation of ‘new learning’ in many Dutch secondary schools, teachers tend to leave practice to the students themselves. Teachers only spend a small portion of the lesson time on classroom instruction and a large part on letting students work on problems independently. However, practice is especially effective when guided by hints or by the teacher. Although this thesis discussed the implementation of a program supporting students, the role of the teacher cannot be eliminated. The success of
the approach described here is the combination of independent work on problems supported by the program and classroom instruction from the teacher.

8.4.3 Supporting the learning of strategic knowledge

This thesis shows that it is possible to improve students’ problem-solving skills with the help of a computer program that supports regular physics education. The just-in-time instruction through hints helped the students to successfully work through novel problems. In this way they experienced an efficient form of learning; they were encouraged to think about what help they needed and chose the instruction that matched their way of thinking. This kind of scaffolding appeared to be more effective than working independently using a textbook and the teacher as a possible background source of help. Some more general characteristics of effective support for problem-solving in physics education can be distilled from the architecture of the program.

Instructional support should be provided through indirect instruction. This is the central assumption in this thesis. In Chapter 1 it was shown that many researchers agree that problem-solving is a skill students have to develop themselves; it cannot be copied from worked examples. Students have to learn to act flexibly when they encounter a problem they have not seen before. They must learn to rely on their skills of reading and analysing the problem, planning and executing a solution strategy and checking the solution. They must be confident that if they do not manage to solve a problem in the first attempt, they can try again by reflecting on their train of thought and finding new ways to analyse the problem or to plan a solution. These abilities and attitudes are best learnt through just-in-time instruction, in which students know they can get help if they become stuck in the solution process. By answering questions (e.g. What do you think the problem is about? Do you think your diagram represents all the relevant features of the problem? Have you ever solved a problem that looked like this one?) and being given content hints, students can be better taught to use the different episodes in problem-solving and learn how to approach problems than through worked examples (Moreno, 2006). In many cases, digital instruction is directed by the computer and only permits one way of solving the problem, or it is a very open system which does not really help students. An important characteristic of the program developed here is that the digital support is sufficiently open for students
to be able to develop their own problem-solving strategies (indirect instruction) but not too open, thus allowing them to find the help they need and not lose track.

Instruction should give opportunity for reflection. The combination of hints (just-in-time instruction) with worked examples afterwards appeared to be effective. Worked examples probably enhance student reflection on the problem-solving process and provide an opportunity to consult alternative ways to solve a problem. Knowing that there are more ways than one will increase flexibility in problem-solving and boost self-confidence. This is especially the case if students understand different ways of solving a problem and are able to weigh the pros and cons of the different solutions. Helping students to solve problems themselves will raise their confidence and improve their self-efficacy. This is especially important for lower-achieving students who may experience many failures and thus lose their self-confidence, which is a very important factor in gaining more problem-solving skills (Mayer, 2008).

8.4.4 Practical remarks about supporting problem-solving
The research reported here covers a period of more than five years, during which considerable time was spent on designing a workable and effective computer program. Considerable time was also spent on constructing a blended learning environment which combined instruction by the teacher and the use of the computer program for individual practice by students. Before the computer program was developed, a paper version of the program was pilot tested to gain an understanding of the strengths and weaknesses of the indirect teaching approach (see Chapter 2). The planning and results of the activities were discussed with a small group of experts who gave their support throughout the research. A fairly good idea of how the program would be used and how it could be implemented in physics lessons was gained before the experiments were undertaken.

For this research project it was necessary to contact not only the teachers at the participating schools, but also the supervisors of the computer rooms in the school in order to make sure Physhint was implemented properly. It was found that it is very important for a successful experiment to have teachers who know the computer program’s content and can relate it to their physics textbook and the lessons they teach. Furthermore, it is important that teachers allocate time for the
students to work independently (in accordance with the lesson plan), oversee the students at work and give directions if needed. Without these necessary conditions the experiments would have failed (see also Ruiz-Primo, Shavelson, Hamilton & Klein, 2002).

This point can also be taken to a more general level. As computers become increasingly common in schools, many materials have been developed to support teaching and learning in schools. However, many schools still do not have the proper facilities to use these materials, or the facilities cannot be configured in such a way that they can be used regularly and without fault during lessons. The problems are often of a technical and pedagogical nature. Technically, the programs are often not tested for use in schools on a regular basis. Pedagogically, the materials often do not fit in with the teaching routines in the classroom. When publishers provide textbooks with additional digital learning materials, use of these materials should be encouraged by offering teachers courses on how to use the materials during class on a regular basis. If necessary, technical staff at schools should be trained in how to correctly install and run a program on the computer server. This thesis has shown that it is possible to design a program that combines the teaching of physics with digitally supported independent student practice in problem-solving. The program worked well in a school context. It is recommended that publishers should take the teacher’s role into account when designing a digital program to support the students’ learning processes, and without doubt a pilot testing of the usability and effectiveness of a program in a school setting is needed before the product is placed on the market.