CHAPTER TWO

Development and test of a prototype program to support problem-solving

2.1 Setting for a new problem-solving program

School practice as outlined in the first chapter suggests that students need instructional support in solving physics problems. The situation in school practice gives the impression that physics teachers are retreating from their role as the first instruction resource and that students have to learn to help themselves by using other sources such as books with model answers. It is therefore important to find means to improve the problem-solving abilities of students without involving the teacher too much. It is desirable to find a way to develop a computer-supported environment in which the students have considerable control and which provides just-in-time instruction. In this way students are encouraged to find solutions to problems independently of the teacher or model answers. The next section looks at what the characteristics of a student-controlled program for problem-solving should be.

As Fullan (1991, 2001) underlines, innovations that fit smoothly into school practice have a high probability of being implemented if teachers agree about their value. The problem-solving program to be developed is designed to keep changes in school practice to a minimum, but to have maximum effect on the development of students’ problem-solving strategies. First, a series of lessons will be presented to let the students acquire basic declarative and procedural knowledge of the subject matter. The students are briefly instructed concerning the whole group, have to do independent work, practical work and a discussion of some of the completed problems. The role of the teacher will be to introduce and teach the subject matter and to guide and monitor independent work. This is more or less the standard practice as described in Chapter 1. Students will then learn how to apply their basic knowledge with the help of a computer program that offers support during problem-solving.

The experiment will take place early in upper secondary level education (fourth year, ages 15–16), because students prepare for their final examinations in the last part (sixth year). In these higher years, students have chosen a stream with specific subjects. About one-third to half of the students in Dutch schools choose a stream which includes physics classes (Tweede Fase Adviespunt, 2005).
2.2 Characteristics of an effective program for problem-solving

For problem-solving, in addition to declarative and procedural knowledge, students need strategic knowledge that tells them how and when to use their basic declarative and procedural knowledge of a certain domain and to guide the solution process. Many researchers agree that improving strategic knowledge is not enhanced in a step-by-step teaching process but rather through indirect teaching. Indirect teaching is teaching that does not tell the students how to solve problems but invites them to find solutions and seek help actively if the solution process is blocked. In the previous chapter, I explained that problem-solving is too flexible a process to be learnt by step-by-step instruction of solution stages. Just-in-time instruction can help the student to continue the solution process if it is blocked. In combination with an evaluation directly after problem-solving, this should give the best results for improving strategic knowledge and thus problem-solving abilities.

For the development of a problem-solving program, I took the program characteristics from the reviews of research by De Corte (2004) and Mayer (2008) as discussed in Chapter 1. In summary the characteristics are:

- offer interesting problems to involve the students
- vary the problems and focus on well-defined skills
- choose a specific domain and relate knowledge to a general problem-solving framework
- give instructional support through indirect teaching
- give ample opportunity for reflection and discussion
- practise problem-solving
- improve the self-efficacy of the student.

Later in this chapter I will discuss how these characteristics will be used in the problem-solving program.

Because I wanted to test the program in experiments, some specific conditions also have to be taken into account:

- the program should be implemented in regular school practice and should account for constraints concerning time and the computer facilities available in schools
- teachers should be able to implement the program without extensive in-service training in order to ensure a sufficient number of teachers.
The characteristics of effective problem-solving programs for science education were discussed in the previous section. One characteristic is to restrict problem-solving to a domain and a subject. The topic of forces is one of the most researched in science education (Malony, 1994; Pfundt & Duit, 1991). Although students might develop misconceptions while learning this topic (Malony, 1994), results from research show that the misconceptions can be overcome through proper teaching and that regular school problems can be satisfactorily solved (Martin, Mullis, Gonzalez, & Chrostowski, 2004). The topic of forces is well-defined and can be taught in a series of lessons requiring conscious problem-solving by students.

A second, more practical, argument for choosing the topic of forces is the moment at which it is taught in Dutch schools. In most schools, it is scheduled after kinematics, which makes it possible to pre-test problem-solving abilities. Moreover, because the topic of forces is a prerequisite for other topics in the overall physics programme, many schools do not want to schedule it late in the fourth year programme.

2.3.1 Declarative and procedural knowledge on the topic of forces

When the topic of forces is taught in upper secondary school, it is usually combined with the topic of torque. Figure 2.1 presents nationally determined learning outcomes from the national syllabus (Ministerie van Onderwijs en Wetenschappen, 1998).

This is a limited list of concepts. These concepts and their interrelationships in the topics of forces and torque were analysed in order to gain a better understanding of the subject knowledge involved in the project. The analysis generated two concept maps (Novak, 1990) that were used as guidelines to determine the choice of material for the project. The analysis is depicted in Figures 2.3 and 2.4. These maps show the formulas as well as the relationships between the different formulas and ideas as incorporated in the subject.

To develop the concept maps I began by writing down the explicit issues in the syllabus, such as ‘Newton’s laws’ or adding and resolving vectors. I also added standard situations often used in lessons and examinations (e.g. horizontal throw), basic mathematics (e.g. goniometry) and explicit concepts required for this subject but already learned in an earlier subject (e.g. velocity-distance-time).
The most common, important relationships between the different items completed the map. In this way two concept maps were worked out for the items of forces and torque. Relationships between both maps (forces and goniometry) can be found on some points. Figure 2.2 shows an example (a problem involving the friction on a sledge) for which it is important to understand the relationships between the different items.

A sledge with mass 25.0 kg is pulled at a constant speed over a flat surface. This is done with a rope. The rope is at an angle of 37 degrees above the horizontal. The force pulling at the rope is 64 N.

Calculate the friction working on the sledge

Figure 2.2: Problem as taken from Middelink et al. (1998)
The sledge is pulled at a constant speed with a rope held at an angle of $37^\circ$ with the ground. The first thing students need to understand is the concept that the total force on the sledge is zero (because speed is constant), which means applying Newton’s first law. However, to solve this problem, students need to split up the pulling force at the sledge into a horizontal component working along the ground and a vertical component working straight upwards. The idea is that, because of the constant velocity the horizontal component is equal in size and opposite in direction to the frictional force of the snow. Splitting up the pulling force into the two components is done using goniometry. The concept map in Figure 2.3 shows that the concepts needed to solve this problem can be found in the upper-left corner of the concept map, and that Concepts 1, 10 and 4 are used.

However, if we look at how students have to solve this problem, we see that they need to know not only the points in the map, but also the relationship between different points. The problem therefore requires both the use of one or more concepts and an understanding of the relationships between the different concepts as mentioned in the syllabus.

All points on the concept maps can be considered declarative knowledge, and partly procedural knowledge. Students should learn to use the formulas in the concept maps and the procedures incorporated in these maps. But as the example shows, this is not enough. This task requires the student to make a sketch of the sledge in order to understand the forces exerted on it. The student may be able to solve the problem using this insight. That is why we have to find out which hints may help when students start to solve novel problems. Section 2.4 explains how hints can be developed.

On the next two pages:
Figure 2.3: Concept map of Vectors and Forces
Figure 2.4: Concept map of Torque
Newton’s first law of forces
If the resulting force = 0 (Newton) then the acceleration also = 0 (m/s²)
Definitions + property variables:
Fres = total of all forces
Fmusc = muscular strength, Fg = gravity
Ffric = friction, Fn = normal force
Fspring = force of a spring

Calculated resulting force
Fres = 0
Fres ≠ 0

Newton’s second law of forces
Fres = m . a
Definitions + property variables:
Fres = graphical addition of all forces [N]
m = mass of accelerated object [kg]
a = acceleration of object [m/s²]

Combination of law of gravity and Newton’s first law of forces

Horizontal throw
Definitions + property variables: falling object with horizontal starting velocity is described by a parabolic function

Resolving a vector (force)
Definitions + property variables:
Pythagoras’ theorem
Parallelogram method
Trigonometry

Adding two vectors (forces)
Definitions + property variables:
Direction is important
Pythagoras’ theorem
Tail-to-tip method of adding vectors
Parallelogram method
Trigonometry

Velocity is distance per time unit
(v = Δ s / Δ t) Definitions + property variables: v = velocity [m/s], s = distance [m], t = time [s], Δ = difference between end and beginning

Confusing a with g, what are the differences, what are the similarities? Relationship between a and g²

Necessary for understanding a (acceleration).

Combination of law of gravity and Newton’s first law of forces

Force
Definitions + property variables:
Direction and size
Same direction: sum
Opposite direction: difference

Necessary for

Calculating the resulting force

Necessary for

Goniometry: sin, cos, tan
Pythagoras’ theorem
Definitions + property variables:
Only when: in a right triangle!
a² + b² = c²
sin α = opposite side/sloping side
cos α = adjacent side/sloping side
tan α = opposite side/adjacent side
α = sin⁻¹ opposite/sloping side
α = cos⁻¹ adjacent/sloping side
α = tan⁻¹ opposite/adjacent

Calculating resulting force

Combination of law of gravity and Newton’s first law of forces

Necessary for
**Definition of torque**

\[ \vartheta = F \times d \]

**Definitions + property variables:**
- \( \vartheta \) = torque of a force \([\text{N.m}]\)
- \( F \) = size of the force \([\text{N}]\)
- \( d \) = lever arm
  - (lever arm: the perpendicular distance from the axis of rotation to the line along which the force acts)

11. **Net torque**

Sum of the torque: \( \Sigma M \)

**Definitions + property variables:**
- Counterclockwise torque is taken positively
- Clockwise torque is taken negatively

13. **Object in equilibrium**

If: \( \Sigma F = 0 \) and \( \Sigma M = 0 \)

**Definitions + property variables:**
- \( \Sigma F \) = sum of all forces as a vector
- \( \Sigma M \) = sum of the torque in relation to the axis of rotation

14. **Alternative for ‘object in equilibrium’**

**Choice of axis of rotation**

For an object in equilibrium, every point can be taken as a turning point.

**Definitions + property variables:**
- See 11
- Alternative for a rule as written down in the book \((M = 0 \text{ and } \Sigma F = 0, 14)\). This alternative is taught? in the lessons

15. **Lever arm \((d)\)**

The lever arm is the perpendicular distance from the axis of rotation to the line along which the force acts.

**Definitions + properties variables:**
- Working line: line along which the force is working
- Axis of rotation: defined point which lies in the middle of the rotation

12. **Centre of gravity of an object**

Definitions + property variables:
- The centre of gravity of an object is the centre of mass of this object
  - For symmetric objects the centre of gravity can be found by taking the intersection of the symmetry lines
  - For non-symmetric objects the centre of gravity can be found by taking the intersection of two perpendicular lines

10. **Trigonometry and ‘resolving a force in its components’**

See first diagram; concepts 1 and 9
- Trigonometry or Pythagoras’ theorem is often used to calculate the lever arm (= concept 1)
- Force can also be resolved in components along and perpendicular to working line of the force (trigonometry and/or Pythagoras’ theorem is needed)

11. **Force**

From first diagram, see concept 8.

**Definitions + property variables:**
- Force has a magnitude and a direction (= concept 8)
2.3.2 Use of a textbook to teach

In the section above I discussed the knowledge necessary to understand concepts and relationships about forces and torque. In this section I will discuss the type of textbook and problems that can be used to teach declarative and procedural knowledge as well as problems for teaching strategic knowledge about this topic. The textbook plays an important role in science teaching. Instruction is done by the teacher and problems to be solved are mainly derived from the textbook the school uses to teach physics.

Some conditions have to be taken into account when choosing a textbook as a basis for problem-solving related to forces: these include coverage of the topic (number of chapters), concepts and relationships presented (completeness), availability of self-instructive information needed to solve the problems (amount of instruction), availability of half-open and novel problems in the textbook, and use of the textbook in Dutch schools (dissemination among Dutch schools). The textbook by Middelink et al. (1998) best fits these conditions. An examination of the availability of information and the nature of the problems had shown that three textbooks could be used in the study. However, when the number of chapters needed to teach the subject were taken into account, Middelink et al. emerged with the best choice of method. If the topic spans more chapters, many schools split up the topic of forces within the curriculum, and are thus not suitable for our experiment. This method also has a very high degree of dissemination among the schools, which is another positive point for Middelink et al.¹

The textbook *Systematische Natuurkunde* (Systematic Physics) by Middelink et al. covers the topic of forces and torque in a single chapter. The authors of the textbook estimate that the topic requires about 15 lessons of 50 minutes. The chapter in the book contains more tasks than students need to work out in the time planned. When making a selection of the tasks, coverage of the concepts and relations as presented in Figures 2.3 and 2.4 were considered, as well as student workload. Most selected tasks came from the end of the chapter because these contain the more complicated problems. Because these tasks are semi-structured, they require more complicated solution strategies and more subject matter. For the first, preliminary experiment, 73 semi-structured tasks were selected from the

¹ Although dissemination among schools is not public knowledge, I found through surveys at teacher conferences that the Middelink et al. textbook (1998) was in use in more than half of secondary schools in the Netherlands.
textbook. An example of a semi-structured problem is given in Figure 2.5 in the next section. Table 2.1 presents the complete list of tasks.

Table 2.1 Selection of tasks chosen from the textbook

<table>
<thead>
<tr>
<th>Planned problems</th>
<th>Introduction of topics, including concept numbers as found in Figures 2.3 and 2.4.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Problems: 1–4</td>
<td>Principle of superposition:</td>
</tr>
<tr>
<td></td>
<td>- Vector versus scalar</td>
</tr>
<tr>
<td></td>
<td>- Composing forces, goniometry and construction 1. 8.</td>
</tr>
<tr>
<td>15 Problems: 5–19</td>
<td>Resolving forces in rectangular components</td>
</tr>
<tr>
<td></td>
<td>- Resolving forces in other components 2. 6. 9.</td>
</tr>
<tr>
<td></td>
<td>- Horizontal throw 7.</td>
</tr>
<tr>
<td></td>
<td>- Torque in context situations 14.</td>
</tr>
<tr>
<td></td>
<td>- Torque on pulleys 15.</td>
</tr>
<tr>
<td>8 Problems: 66–73</td>
<td>Fixed pulley versus loose pulley</td>
</tr>
<tr>
<td></td>
<td>- Calculation of forces at a turning point</td>
</tr>
</tbody>
</table>

2.4 Development of a prototype

After choosing the subject matter, the next step was to implement the theory of problem-solving instruction in such a way that it enables students to solve problems individually with the help of supportive just-in-time instruction.

The structure of the new program uses Schoenfeld’s (1992) problem-solving episodes: orientation (Survey), analysis (Tools), planning (Plan), check and reflection (Model answer). The instruction that goes with these episodes can help students to solve problems more systematically (see Section 2.2). The hints are not presented automatically but as a menu that students can select from.

When choosing help, students have to select one of Schoenfeld’s episodes. In order to do this consciously (e.g. use their strategic knowledge), they have to decide which episode they have reached the moment they need help. Each episode covers different kinds of help. For example, the first episode, Survey, represents help at the beginning of the solution process and gives hints for surveying the problem. This could be advice to make a sketch of the problem situation, or to
calculate a simpler situation in order to gain an idea of what the problem entails. In the second episode, *Tools*, the student can find missing information needed for solving the problem. *Plan* gives hints if students are completely stuck and gives them part of the solution process.

The program gives students as much room as possible to develop their own problem-solving strategies, which is why the problem-solving framework (menu of hints arranged in accordance with Schoenfeld’s episodes) is presented at the moment students need it. Students have three opportunities to answer. During the problem-solving process they are free to choose from the available help in the menu. After problem-solving, they have an opportunity to study model answers, which are worked examples of the solution to the problem. In most cases, more than one solution is offered to show that there are more ways to solve the problem, depending, for instance, on the representation of the problem situation.

This structure supports students’ development of strategic knowledge. For example, if the students do not comprehend the problem description and choose help that goes with the *Survey* episode, they understand how to structure a solution process. The hints with the episode provide both subject knowledge (declarative as well as procedural knowledge) and more common strategic suggestions such as to make a drawing or calculate a simpler example (strategic knowledge), which can help students to represent the problem correctly.

Several researchers have emphasized that in learning to solve problems there is a great need to link students’ strategic knowledge to declarative and procedural knowledge (see Section 2.2). In Chapter 1, I discussed seven characteristics of effective programs for problem-solving. This section will argue how these characteristics can be found in the computer program.

*a) Offer interesting problems to involve the students.* From Middelink et al.’s textbook (1998), I chose problems with interesting contexts referring to concrete situations that the students could understand by looking at pictures representing the problem situation. Students are expected to be motivated to accept the task and try to seek a solution actively, as the tasks are in line with what will be expected of them in school tests.
b) Vary the problems and focus on well-defined problem-solving strategies. The problem situations in the textbook vary greatly. I picked those problems that refer to knowledge of forces and/or torque, as well as to strategic knowledge.

c) Choose a specific domain and relate knowledge to a general problem-solving framework. The learning environment is embedded in the specific domain and subject of forces and torque. This limited domain enables students to acquire declarative and procedural knowledge in such a way that the development of strategic knowledge will not be hampered.

d) Give instructional support indirectly. The question of giving support is twofold: how and when should support be provided? In Chapter 1 we saw that most researchers advised that direct support is not in line with the nature of problem-solving. I therefore opted for indirect support, which allows students to choose support when they need it. Such support can be given before, during or after problem-solving. The literature on supporting problem-solving shows that support before problem-solving can be helpful for learning declarative and procedural knowledge, but that students need support during and after problem-solving when learning to develop strategic knowledge. For the program I therefore chose a combination of support during and after problem-solving.

e) Give ample opportunity for reflection and discussion. Normally, reflection and discussion is expected in a teacher-student interaction or, for example, in collaborative learning. For our program, reflection on the solution process is organized by letting students choose hints after that part of the solution where they became stuck. By comparing the hints with their own solution, students see where they got lost and are able to continue. The program also offers different model answers to enhance reflection.

f) Practise problem-solving. For successful training of strategic knowledge, practice is an important aspect of acquiring problem-solving skills. The program sequences problems from less complex to more complex so that students who have not fully mastered the basic domain knowledge can also start practising problem-solving. Students spend 10 lessons, practising on a total of 73 novel problems. Practice
starts early. In most of the 14 lessons, basic declarative and procedural knowledge is first taught and then students are asked to apply this knowledge in a program with novel problems they have not yet faced.

g) Self-efficacy. Self-efficacy encourages students to resolve problems efficiently. The program offers hints to students who are unable to finish a problem, after which students may be able to finish it after all. We expect that – compared with regular education – the support provided will help students to finish more tasks, which can improve their self-efficacy.

Figure 2.5 gives an example of a problem from the program. It shows how some of the seven design characteristics are incorporated. First, the problem is presented to the student, with episodic help provided in a menu below the problem.

The figure shows a cord from which a weight of 50 N is hanging in the middle. Calculate how large angle $\alpha$ should be in order to let the weight hang and not break the rope if you know that the rope breaks at a tension of 120 N or more.

What are you having difficulty with and what help do you need?

<table>
<thead>
<tr>
<th>Survey (two hints)</th>
<th>Tools (three hints)</th>
<th>Plan (three hints)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make a drawing</td>
<td>Using a parallelogram</td>
<td>Parallelogram becomes diamond</td>
</tr>
<tr>
<td>Why does the rope break?</td>
<td>Extra lines in the graph</td>
<td>Argumentation</td>
</tr>
<tr>
<td></td>
<td>Make a sketch of weight</td>
<td>Sketching the forces</td>
</tr>
</tbody>
</table>

Figure 2.5: Problem from the experiments with help for different episodes

Schoenfeld’s episodes can be recognized in the list of hints. Each key word in the list refers to a hint which might help the student to solve the problem. The survey hints are given in Figure 2.6.
The text of the hints is kept short. Where possible, visual representations are provided to make the hints as comprehensible as possible and to prevent cognitive overload (Clark & Mayer, 2008).

After attempting to solve the problem, students can choose from a menu with short descriptions of three model answers. They can consult one or more of these. The different model answers may cover informal solution methods (such as tables or numerical calculations) or formal solution methods (such as formulas or algebraic equations). The function of the model answer is to support reflection on the solution process. Figure 2.7 gives three formal solutions for the problem in Figure 2.5.
First we explain why the rope can break: If the rope is hanging with less tension, it will hang deeper. Then the constructed parallelogram will be higher and the sides only need to be short in order to make a longer axis. If the cord is hanging with more tension, the forces in the rope will be bigger.

| PS | = | PQ | = | RQ | = | RS |
|    |    |    |    |    |
|    |    |    |    |    |
|    |    |    |    |    |

=> square PQRS is a diamond.

In this diamond the diagonals are perpendicular and cut each other in the middle.

=> PT = TR = |1/2 . Fz |

In ΔPTQ is

\[ \cos \alpha = \frac{PT}{PQ} = \frac{25}{120} = 0.208 \Rightarrow \alpha = 78^\circ \]

Figure 2.7: The three cards with the model answers for the problem in Figure 2.5 on the back
2.5 Test of the prototype

In order to test the usefulness of the instructional design of the learning environment, I decided to first create a paper version and see how well this worked with students (see Driscoll, 2002 on the value of creating and testing a paper version of a program before developing a new computer program). The major point of this test is to investigate whether instruction with hints helps students to solve the problems and whether use of the learning environment helps them understand the framework and when to use which hint. Through the test of the paper prototype, I wanted to evaluate the suitability of the problems, the suitability of the hints and the framework system used. More specifically, I addressed the following questions:

• First, are the problems satisfactory so that students understand them as intended and are motivated to solve them? Are problems satisfactory so that students really need hints to solve them?

• Second, do students understand the interface of the framework consisting of hints structured according to the episodes and do students understand the hints? While solving a series of problems, do students progress in their solution process when using the Survey, Tools or Plan hints? What modifications are needed to make the hints more usable during problem-solving?

As a result of this analysis the explanations of the problems and the hints will be adapted if necessary.

2.5.1 Research design of the pilot study

For this preliminary research a speak-aloud approach was used in which students were invited to read and solve a problem aloud and their spoken language was recorded on videotape. Eighteen students (fifth year of upper secondary school, pre-university level) from a school in the Netherlands were invited to individually work out a selection of the problems. Five students were male and thirteen female. The students had worked through the chapter about forces and torque in the book and had reached the necessary level of content knowledge when they took part in the pilot. All students had achieved sufficient results for their exams for this part of the textbook, ranging from 6 to 8.5 (on a scale from 1 to 10). In order to guarantee
that the problems used in the experiment were new to the students, problems which were not covered in the lessons were selected.

The students were invited to talk as much as possible about the way they were working out the problem, including the difficulties they met and the choices they made. A total of 73 problems were tested. Each student solved eight to nine problems and each problem was done by two students. The problems, as well as the help for each problem, were offered on cards. The number of the task and a short description of the help, including the names of the episodes (Survey, Tools or Plan) could be found on the back of each card. At the beginning of the solution process, the student could only see the problem; only the back of the other cards was visible. The students worked out the problem using pencil and paper. While trying to solve the problem, they were allowed to turn over one of the help cards. The students were asked to explain their choice of card and say whether the hint helped them in the solution process.

The students received a short training session in how to use the hints. After that, they had to solve some complex problems under the supervision of the researcher. If a student did not succeed during problem-solving, the researcher first asked standard questions in order to gain insight into missing information on the cards. Questions included: What do you think went wrong? Did you understand the question correctly? Did you use all the data in the problem description? Once the student answered these questions, the researcher asked which hint the student thought would best help him or her on the way. If no more help was available, the student was given additional help from the researcher in order to finish the problem. In all cases in which the student did not manage to solve the problem independently, I concluded that the help provided for that problem had to be adapted.

The transcripts of the video recordings mostly involved student explanations for the different steps they took and the hints they used. For each problem, the researcher logged data about:

- whether the problem was worked out correctly and in how many trials
- the hints that were used
- whether the hints helped students to progress in their problem-solving, and
- whether students consulted the model answers after the problem was finished.
2.5.2 Results of the test

During the test I found that some problems could be solved without the help of hints. However, in most cases the students did not succeed in working them out independently. The students often made a first attempt without consulting the hints but came up with an incorrect answer. They then tried again with the help of the framework offered by the hints. Table 2.2 gives an overview of how the problems were solved. Each problem was attempted separately by two students, bringing the total number of trials to 146.

Table 2.2: Percentage of problems unsolved and solved with and without hints

<table>
<thead>
<tr>
<th>Total number of problems (each problem was tried out by two different students)</th>
<th>Number of problems which could not be solved by one or both students</th>
<th>Number of problems solved by both students; no hints were needed</th>
<th>Number of problems solved by both students; one or both students used hints</th>
</tr>
</thead>
<tbody>
<tr>
<td>73</td>
<td>24 (33%)</td>
<td>19 (26%)</td>
<td>30 (41%)</td>
</tr>
</tbody>
</table>

Of the 73 problems, 19 (26%) could be solved without help by both students. At first sight, these problems seem to be too simple. This came as no surprise because the problems were mainly ones from the beginning of the lessons on forces and the students participating in this study had all finished these lessons with good results. In total, 30 problems (41%) could be solved by at least one of the students but only after consulting one or more of the hints. These problems seemed to be difficult enough for learning to solve problems and the hints seemed to provide the student with appropriate support. The remainder of the problems (24, or 33%) could not be solved by one or both students, even after consulting the hints. This means that in at least one of the two trials the student did not manage to solve the problem without the researcher’s help. However, if we look at trials of the students solving these problems, the level of the problems does not seem to be the reason for this failure. Many problems could still be solved after some help from the researcher. This means the hints should be improved to help future users to solve the problems with the hints.

An analysis of the students’ use of hints was also undertaken. Table 2.3 shows the percentages of problems for which the different kinds of help were consulted by at least one of the two students. For clarity, unlike Table 2.2, which looked at problems needing adaptation and which therefore included every
problem with one or more mistrials and in need of adaptation, this overview gives overall averages for the use of support and the number of problems which succeeded.

Table 2.3: Percentages of trials in which cards were used

<table>
<thead>
<tr>
<th>Total number of trials</th>
<th>Percentage of trials with Survey consulted</th>
<th>Percentage of trials with Tools consulted</th>
<th>Percentage of trials with Plan consulted</th>
<th>Percentage of trials with at least one hint consulted</th>
<th>Percentage of trials with model answer consulted</th>
<th>Percentage of trials with problem solved</th>
</tr>
</thead>
<tbody>
<tr>
<td>146</td>
<td>32%</td>
<td>40%</td>
<td>37%</td>
<td>70%</td>
<td>100%</td>
<td>79%</td>
</tr>
</tbody>
</table>

Hints for Survey, Tools or Plan were used for 32%, 40% and 37% of the tasks respectively. These percentages show that each type of hint was used, although not in the majority of cases. With at least 70% of the tasks, one or more of the hints were used in one or both trials. If students used one hint, they often also consulted another type of hint (51% of the trials for which one or more hints were consulted). All students used the model answer after finishing a problem. In total 79% of the problems were finished correctly.

The reported facts should be seen in the light of this study. The cards with hints were used in one-on-one situations, where students were asked to work out problems under the supervision of a researcher, and where the solution process was recorded on video. The situation might have influenced the behaviour of the students in that they consulted hints and used model answers more than they would without the researcher present. As reported in Table 2.2, 67% of the tasks were solved by both students, with or without the support of hints. This means that from the preliminary research I found no reasons to adapt this 67% of the problems. Some problems were solved by one of the students, but not by the other. Of the total number of trials, 79% were successfully completed without the help of the researcher. Another 3% of the tasks could be solved with the help of questions asked by the teacher. The remaining 18% of the tasks could only be solved with the researcher giving extra hints. The system did not work in 21% of the trial problems. In those cases, the help needed to be adapted in such a way as to help future users. I will discuss below the adaptations needed to improve the system. However, I will first give some examples of how students work with the hints, as
this will provide indications for how to adapt the set of hints. The first example is a student who fails to solve a problem despite using hints, and the second a student who succeeds in finishing a problem with the help of hints.

**Problem unsolved although hints are used:**
The first case is Emily (students’ names have been changed), who was trying to solve a problem about forces. This is a complicated task for which many hints are available. But not enough, as can be seen in the transcript (R= researcher and E = student).

*Transcript of Emily trying to work out problem 30:*

**E. takes the problem and reads:**
Problem 30: For this problem, look at the figure. The mass of the ropes can be ignored when compared with the masses of blocks A and B.

Calculate the normal force working on B.

**E. Copies the drawing onto her paper.**
R. You are allowed to say as much as possible; everything is meaningful to me.
E. OK. Then I’ll make a drawing first.
R. Yes, very good.
E. The question is to calculate the forces on A and B. But I don’t know that formula anymore. So first let me take a look at a hint.
R. OK. You already have an idea about which hint you need?
E. Yes, a formula, a formula, I think.
E. Turns over Tools hint: forces?
In any case, gravity and a force of tension works on the blocks, and sometimes also a normal force.
E. Force of tension... The forces on A and B...
E. Turns over Plan hint
Copy the figure, and draw in your figure the forces working on block A and also the forces working on block B. The block which first needs to be considered is the one with only working gravity and the force of tension on it.
E. The block which first needs to be considered is the one with only gravity and force of tension. That’s that one (points at block A)
E. Which first needs to be considered… So first block A.
E. Writes: Block A:
E. But then I still do not know the formula.
E. reads the front of a hint card: Which mass to be calculated first?
E. turns over Survey hint: Tension in a cord
Everywhere in the cord, the tension is equal.
E. Is equal, everywhere in the cord. I assumed that already, I think.
R. OK.
E. Yeah, then I have to turn over another one.
E. Turns over Survey hint: which mass should be calculated first?
The $F_{\text{res}}$ at A and B is 0 N, because the system is not moving. You can first calculate the situation for block A.
E. Oh yes. $F_{\text{res}}$. Oh yes, isn’t that the formula with force and mass is force and mass? Wasn’t it $F = m.a$ or something like that?
E. writes: $F_z = m.g \ F_z = 4.981 = 39 \text{ N}$.
E. 39 N. But then I still have to calculate the tensional force. Yes, but then first I will calculate B. Because in that one we also have a normal force. Let us first calculate gravity.
E. writes: block B = $F_z = 6.981 = 59 \text{ N}$.
E. But I don’t have any idea how I now calculate the normal force… Oh wait, um. The forces on each side have to be equal of course. I think, yes.
E. takes Survey hint: Graphical
Copy the figure, and draw in your sketch the forces as working on A and B.
E. I’ve already done that. Then how to calculate the normal force? Or the tensional force? Because I don’t know if um … I have to incorporate the pulley … And I have been running through my hints.

The student gives up because the hints do not seem to be sufficient for her to finish the task. She has started running out of hints and cannot find a way out. What seems to disturb the solution process is that the student does not see the meaning of the hints. Although the hints point to a graphical way of solving, or partly solving, the problem, she still looks for a formula (which does not exist in the way she needs it). This student might be helped by more general hints that
encourage her to reflect on her solution process and to look for different ways of solving a problem. In this case, this would involve trying to fill in formulas and making sketches to clarify and therefore solve the problem. This problem thus requires adaptation in the form of more Survey hints to encourage the student to elaborate the problem further.

Problem solved with hints:
Next, the case of Wendy is discussed. This is a good example of a student who manages to finish a task by using hints. She first reads the problem and immediately looks at a hint with the episode Tool. She then tries an answer, which proves to be incorrect. Then she tries again. The transcript starts at this point. (R = researcher and W = student).

Transcript of Wendy, trying to solve problem 21 for a second time.

Problem 21:
For 60 seconds different forces work on an object. During these 60 seconds, the object keeps moving in a straight line. The velocity of the object during these 60 seconds is plotted on the figure on the right. During the first period, a force of 0.30 N works on the object.

Question: What is the mass of the object?

R. OK. If I tell you that this answer isn’t correct.
W. OK.
R. What could you do?
W. Find the formula for acceleration … According to me this is the first period.

Points at the first part of the graph.
W. Let’s take a look at that.
Takes Survey hint: Acceleration?
From the first part of the graph you can determine the acceleration by using \( a = \Delta \frac{v}{\Delta t} \)
W. Yes, that is what I did wrong: the difference between um …
R. You can do it again.
W. Yes, ...um. Then it will become the same, except that I have to divide it through ...
R. Yes, exactly.

*Writes* \( a = \Delta v / \Delta t \)

\[ a = \frac{3}{15} = 0.2 \]

\[ m = \frac{0.3}{0.2} = 1.5 \]

W. Then we get a mass = 1.5
R. Very good.

Since Wendy’s first answer was not correct, she became confused and decided to take a second hint. The hint shows she used an incorrect version of the formula, and in the second trial she succeeds. This student thus needed help, but at the level of declarative knowledge. In this case, the student was helped, but the question remains as to whether her strategic knowledge benefited from this help.

In 32 of the 146 trials the problems were not solved by the students. These unsuccessful trials covered 24 of the 73 problems in total. The two examples given above represent two different ways in which students failed. In order to show how support needs to be adapted, all failures and possible solutions were classified, as can be found in Table 2.4.

<table>
<thead>
<tr>
<th>Description of reason</th>
<th>Total times counted</th>
<th>Number of problems</th>
<th>Possible adaptation of the program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of content knowledge</td>
<td>16</td>
<td>14</td>
<td>Extra hint for Tools</td>
</tr>
<tr>
<td>Problem too difficult to solve</td>
<td>6</td>
<td>4</td>
<td>Extra hint for Plan (alternative way of solving the problem)</td>
</tr>
<tr>
<td>Not understanding problem – no overview</td>
<td>4</td>
<td>3</td>
<td>Extra hint for Survey (alternative way of analysing the problem)</td>
</tr>
<tr>
<td>Not understanding problem – problem description is ambiguous</td>
<td>3</td>
<td>3</td>
<td>Adaptation of description of problem</td>
</tr>
<tr>
<td>Miscalculation</td>
<td>2</td>
<td>2</td>
<td>Stimulation of monitoring, improving hints for Plan</td>
</tr>
<tr>
<td>Confusion of terms by the student</td>
<td>1</td>
<td>1</td>
<td>Stimulation of monitoring, improving hints for Plan</td>
</tr>
</tbody>
</table>
From the 32 unsuccessful trials (21%), half could be solved with an extra hint providing extra declarative and/or procedural knowledge. There are many reasons for student failure in the other half. Sometimes a student did not understand the problem because the question was not well formulated. After an explanation of the question by the researcher, the student was able to solve the problem. However, in some cases, even after hints from the researcher, students were not able to solve the problem. A more elaborate discussion with the students showed these problems to be suitable for the project, but the students could not solve them because they had finished the chapter some time ago. If they had worked though the chapter more recently, they would have been able to finish these problems. In order to meet the difficulties of future students, an extensive plan could be given, which needs to be one of the options under Plan.

2.5.3 Conclusions about the prototype of the program

The first question is whether the problems are satisfactory so that students are motivated to solve them and whether they can only be solved with the help of hints. The second is whether the hints improve students’ problem-solving (do hints help?). My impression was that the students were motivated to solve the problems. They seemed interested in the context and understood the issue involved in most problems. Strikingly, 26% of the 73 chosen problems were too easy for the students and students did not need the hints to arrive at a correct answer. Thirty of the problems (41%) were solved with the help of hints and 24 (33%) were too difficult to solve for one or both of the students in the experiment. The hints did not provide enough help for them to reach a final solution. It seems that some hints had to be improved in order to make the problem representation or solution processing feasible for students. In some cases, a change was made in the number of hints. Five tasks which appeared too simple were removed. In order to guarantee coverage of all concepts, twelve new problems were included in the definitive set. The transcripts showed that some problem situations were poorly represented and the explanations accompanying these problems were revised.

The students understood the interface of the framework. The students understood most of the hints and were guided by them to the correct solutions for most problems. With regard to the total number of problems solved without hints, it should be borne in mind that the students in this study had already finished the
textbook half a year earlier and had therefore mastered the declarative and procedural knowledge. This may explain why they needed help for only 74% of the problems. It indicates that they still remembered much of the knowledge about the topics of forces and torque. We emphasize that the time period between teaching declarative and procedural knowledge in the pilot experiment differs from that used in the later experiments, in which the teaching of this knowledge and problem-solving with the program will occur simultaneously. I was aware of this but made the choice for practical reasons. Nevertheless, I believe that the information from the pilot did meet the aim of evaluating the problems and hints.

2.6 Recommendations for the instructional design of the computer program

On the basis of the prototype test it was decided that the program set-up with cards would be developed into a digital web-based version, but based on the same framework. The program would provide the problems, a help menu with hints, an option to check answers, and a menu with model answers.

The computer version will start with an introductory screen on which students can choose the problems. The introduction page will also provide an overview of the problems already completed (ordered into solved and unsolved). During problem-solving, students will also be able to choose additional instruction by clicking on a toolbar with short descriptions of different kinds of hints available. The hints are again: Survey (Schoenfeld’s ‘read’ and ‘analyse’ episodes), Tools (‘explore’) and Plan (‘plan’). As in the cards experiment, by being offered hints for each episode and using different solution methods, students can continue the solution process and find a solution.

After reading a hint, students will be able to return to the hints menu by clicking on BACK. After answering, they will be given an opportunity to check and reflect on their solution (‘verify’). They have three opportunities to check their answer and may continuously consult the hints. After giving a correct answer or after the third attempt, students will receive a menu with descriptions of worked examples. They can consult one or more of these model answers. The different worked examples may contain informal (table, numerical calculation, etc.) or formal solution methods (formula, algebraic equation, etc.). The function of the worked examples is to support reflection on the solution process.
The program’s user interface will be kept simple and will contain only the necessary information. The problem is displayed on the left-hand side of the screen and the menu with episodes and their hints on the right-hand side. The functions in the program are shown in Figure 2.8. If a student clicks a hint, the information will appear to the right of the problem description and cover the menu. In this way the problem and hints are on the same screen and the student can move back and forward from problem to hint. After solving the problem, the help menu on the right changes to a menu with short descriptions of the different model answers, so that the different model answers can be chosen.

![Diagram of the program's user interface]

Figure 2.8: Starting screen of the program