Improving Help-Seeking Behavior for Online Mathematical Problem-Solving Lessons

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Abstract

The present study investigated if students change their use of heuristics and help-seeking behavior during a two-lesson course. This course was designed to give students the opportunity to solve mathematical problems with help use through heuristic trees and a help-seeking model. During the course students worked on mathematical problems after they watched a video about the desired behavior in an online learning platform. Students can ask for pre-programmed help: hints and heuristics are available for each of the usual phases of problem solving. While working on a problem students made use of a model that supported them to seek help in a right way.
We analyzed student questionnaires, working sheets for the help-seeking model, and student's use of hints and results on the problems. The results are as follows: students worked with concentration and enthusiasm; students were seeking more digital help when the difficulty of the problems increased; the specific hints were clear to students; the occurrence of help-abuse is negligible; at least 21% and a maximum of 71% of the students reported they have changed their approach to mathematical problem solving. Despite our efforts to motivate students to reflect and generalize their results after solving a problem, they did not. Unfortunately our attempts to measure compression of knowledge did not succeed.

Keywords: hints, heuristics, heuristic trees, help-seeking, help-seeking model, problem-solving, self-regulation, online learning platform, compression

In a complex and dynamic society students should learn to think flexibly and apply metacognitive skills (Kuzle, 2013). Through problem solving students can acquire and demonstrate these skills. Problem solving has become important in today's education, but teaching problem-solving skills turns out to be an educational challenge (Kuzle, 2013). Students find it difficult to analyze and fully understand the problem. Additionally, they find it hard to devise and analyze plans. Finally, after executing a plan, they are unable to evaluate the results.

Self-regulation is essential for problem solving (Schoenfeld, 1985), because it is important for students that they can control their own thoughts. Self-regulation is defined by Zimmerman (2000) as: "Self-generated thoughts, feelings, and behaviors that are oriented to attaining goals" (p. 14). Self-regulation is a self-directive process that is valuable to function in today's society after education (Zimmerman, 2002).

A key self-regulatory skill is help-seeking (Newman, 1994). Help-seeking is the ability to ask for help when needed from persons or online learning platforms (Karabenick & Berger, 2013). Effective help-seeking leads to better learning outcomes (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003). To effectively use help tools in online learning platforms students need to demonstrate self-regulatory skills. Nevertheless, they experience difficulties in effectively regulating their own learning in online learning platforms (Schwonke et al., 2013). Students do not effectively use the offered help, either by using no help at all or overusing the help offered (Aleven, McLaren, Roll & Koedinger, 2006). They do not ask for help when they actually need it, but when they do search for help they ask for more help than is required. One way to ask for more help than required is rapidly clicking through the hints to find the answer in the bottom-out hint (Baker et al., 2008).

For this study an online learning platform was used. We designed two methods of support for students: heuristic trees and a help-seeking model. The course gives students the opportunity to solve mathematical problems while using the methods of support. In this paper we investigate whether heuristic trees and a help-seeking model changes the use of heuristics and help-seeking behaviour. This study has not been done before. The help-seeking model and heuristic trees may structure students' self-regulated help-seeking process.

Theoretical Framework

Problem solving

The phases of problem solving are used in our design to structure the heuristic trees. In this part we explain what problem solving is, which phases it consists of and which components are necessary for problem solving.

According to Schoenfeld (1983, 1985) a problem is a task which difficulty can be seen as non-routine and problem solving is trying to resolve a problem without having a direct method for resolving it. Schoenfeld (1985) identified four components that are necessary for problem solving: (1) the individual's knowledge, (2) the individual's use of heuristic problem-solving strategies, (3) the individual's monitoring and self-regulation and (4) the individual's belief systems. The facts and procedures that the students have access to is part of an individual's knowledge. Heuristics are general rules that are helpful for problem solving. The individual's monitoring and self-regulation is represented by the management of resources and strategies. The individual's belief systems are the perspectives that students have when they do mathematical tasks.

Schoenfeld (1985) described the phases for problem solving as following: read and analyze, explore, plan, implement and verify. Polya (1945) suggested the following components as a part of problem solving: students have to understand the problem, then they have to devise a plan and carry it out, and finally, they have to examine the solution. Carlson and Bloom (2005), among others, have continued the work of several mathematicians. They classified four phases for mathematical problem solving, namely orienting, planning, executing and checking. During the orienting phase Carlson and Bloom observed that mathematicians tried to understand the information in the problem by using their pre-existing domain knowledge. Heuristics supported them during this phase. In the second phase, planning, the mathematicians were using conceptual knowledge and heuristics to form and evaluate their conjectures, while monitoring their own strategies. In the third phase, executing, mathematicians made use of heuristics, algorithms, and computations to construct solution approaches. Their approaches were monitored the whole time. During the last phase the mathematicians were reflecting on the quality of their strategies and products. They checked whether the used strategies and the solution were correct.

Based on this analysis the heuristics are structured in a heuristic tree in the online lesson according to the phases of problem solving: orientation, making plans and execute them and after solving the problem.

Heuristics

Students can ask for pre-programmed help in the online lesson. Heuristics and hints are available. In this section we explain what heuristics and hints are, and which heuristics are used in the online lesson for each phase of problem solving.

Heuristics are general rules that are helpful for problem solving (Polya, 1945), by helping to come up with a suitable approach to solve a problem (Drijvers, 2011). In contrast to heuristics, hints are concrete steps that ultimately lead to the answer of a problem. Table 1 shows the heuristics that we implemented for each phase based on Tak and Bos (2017).

Table 1. The used heuristics in the online lesson

Orientation	-Describe why you cannot solve the problem. Reformulate the problem in your own words. -State the required prior knowledge.

	-Organize the given data and unknowns. For example by putting them in a drawing or table. -Draw help lines if necessary. -Try out actions. - Compare with problems that you have solved before.
Making plans and execute them	-Work from the data or work back from what you have to solve. -Make a drawing to support your approach. -Use algebra. For example: make a comparison and solve it. -First solve a simpler problem or a partial problem. -Gamble a solution and check it. -Proceed clearly and accurately. -Check each step and write it down exactly.
After solving	-Describe which strategy(s) you have used. -Describe what you have learned. -Generalize your answer. -Check your answer. -Try to find more solutions. -Evaluate the process of solving

Heuristic trees

In the online lesson students can solve mathematical problems with help use through heuristic trees. The software offers students help when they have no clue about the next step. This implies that students can continue with the problem-solving process without the help of the teacher, which can be relieving. In the following paragraphs, we describe the structure of the heuristic trees.

In education heuristics can help students in problem solving on condition that they are structured. Schoenfeld (1985) stated: "Many heuristic labels subsume half a dozen strategies or more. Each of these more precisely defined strategies needs to be fully explicated before it can be used reliably by students" (p. 73).

A heuristic tree consists of different branches, each starting with the more general heuristics and ending in concrete hints (see Figure 1). The students can choose for themselves to access the next heuristic or hint. The following design principles are used in the second version of the online lesson to structure heuristic trees:

1. The heuristics and hints are separated in different textboxes to make it clearer and easier to determine from which phases students need help. Students need to use heuristics before getting the more concrete hints.
2. The hints are given based on the heuristics, thereby explaining the use of heuristics, which is important according to Schoenfeld (1985).
3. The hints and heuristics are classified according to the stages of problem solving, which are mentioned in the headings: orientation, making plans and execute them and after solving the problem. In the phase 'making plans and execute them' mathematical hints can be found.
4. As the problems become more difficult, the heuristic trees increase in depth.

The following design principles are taken into account and adapted from the first version:

1. The structure of the tree should represent the logical order of reasoning within a solution model.

2. The various branches should also be ordered following the various stages of problem solving. In general: orientation, planning and acting, reflection.

3. The structure of the tree should also match with the intuitive approach of the problem taken by learners.

4. The order along a branch should be *from* heuristics *to* more concrete hints, thereby explaining the use of the heuristic.

5. The help offered in different branches should be independent stepping stones, in the sense that for the help offered in one branch no information in any of the other branches should be needed.

6. Each click should not give more help than asked for.

7. The formulation before the click should not yet give away the heuristic or hint, but give an indication of what can be obtained. (Bos, 2017, p. 3)

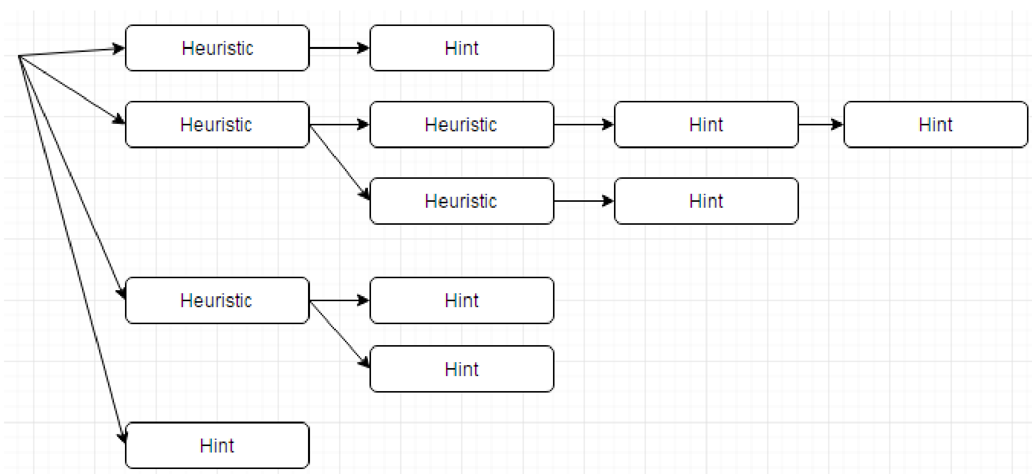

Figure 1. The structure of a heuristic tree. Reprinted from '*Supporting problem solving through heuristic trees in an intelligent tutoring system'* (p. 437) by R. Bos, 2017, in G. Aldon & J. Trgalova (Eds.), Proceedings of the 13th International Conference on Technology in Mathematics Teaching, Lyon, France: Claude Bernard University Lyon 1.

Help-seeking and self-regulation

Help-seeking is a strategy of self-regulated learning (Newman, 2000). Zimmerman stated (1988): "It appears that self-regulated students were not passive learners but actively sought out information and assistance when needed. This is one of the most widely emphasized characteristics of self-regulated learners, and our data support its theoretical importance" (p. 289). Help-seeking can be described as the process where direct help is asked from peers, teachers and other people to overcome difficulties (Karabenick & Berger, 2013). Help can also be requested indirectly by requesting hints and explanations. The help-seeking process consists of several stages: (1) determine whether there is a problem, (2) determine whether help is needed/wanted, (3) decide whether to seek help, (4) decide on the type of help, (5) decide whom to ask, (6) solicit help, (7) obtain help and (8) process the help received. This help-seeking process is integrated in our designed help-seeking model which is used when students solve mathematical problems.

Help-seeking, self-regulated learning, domain knowledge and online learning platforms

Research has been carried out to explore the possibilities of online learning platforms as a tool to improve help-seeking, self-regulated learning and domain knowledge. In the following paragraphs we discuss the results of several studies and how these findings contribute to our design.

Schwonke et al. (2013) investigated if metacognitive support improved learning. Metacognitive support was offered to students in the form of cue cards with texts that supported students to use instructional resources in the online learning platform. Metacognition is evident in self-regulated learning and this study showed that metacognitive support has a positive effect on learning outcomes in low-prior knowledge students. Besides, metacognitive support led to a more selective use of the available help-facilities. Due to these reasons we developed a help-seeking model that assists students in structuring their help-seeking.

Raaijmakers et al. (2017) investigated if self-assessment and task-selection skills could be improved by video modeling examples with heuristic and algorithmic training of self-assessment and task-selection skills. Self-assessment and task-selection skills are part of self-regulated learning (Zimmerman, 2002). Students who received self-assessment and task-selection training by video modeling improved on domain knowledge and on transfer of task-selection skills. This study showed that video modeling examples of self-assessment and task-selection can be effective for improving outcomes of self-regulated learning. Koston, Van Gog, and Paas (2012) also examined the effectiveness of video modeling examples with self-assessment and task-selection training. The video-modeling proved to be successful for student learning and self-regulated learning. To improve the help-seeking process of students, we developed a video that explains the correct help-seeking behavior in the online learning platform.

Aleven et al. (2016) tested if The Help Tutor, a tutor agent that gave in context, real-time feedback on students' help-seeking behavior, helped students in becoming better self-regulated learners and improved their domain-level knowledge. It was concluded that The Help Tutor achieved better help-seeking behavior, which is part of self-regulated learning, but achieved no improved domain-level knowledge. Because feedback about students' help-seeking behavior proved to be effective for better self-regulated learning and increased knowledge, we developed a help-seeking model that supports students in structuring their help-seeking behavior.

Walker, Rummel, and Koedinger (2013) examined the help-seeking behavior of students. They did not provide help in context of on-demand, principle-based help, but they provided help in terms of peer tutoring. Walker tested if the Adaptive Peer Tutoring Assistant (APTA) improves students' collaborative interactions. The APTA discusses the problem steps with students in a chat window. Since the study showed that the discussion of the problem steps offered relevant support and improved student learning, the problem-solving steps are integrated in the online lesson. Each time students note a step to solve the problem, while using algebra as a solution method, they can directly see if their problem-solving step is correct or incorrect.

In these studies research was carried out regarding the possibilities in which online learning platforms can help in improving self-regulated learning and domain-level knowledge. However, it has not been investigated if heuristic trees and a help-seeking model changes the use of heuristics and help-seeking behaviour. The help-seeking model and the heuristics may structure students' self-regulated help-seeking process.

Pilot study

In a study by Bos (2017) about the use of heuristic trees in this online lesson several aspects came forward. Students used either no hints or all at once. Additionally, students had trouble with the difficulty of problems and they found it hard to navigate through the heuristic trees. The online lesson therefore needs to be optimized in terms of self-regulation, motivation and navigation. This study will focus on self-regulation. You can see an example of a problem in the online lesson in Figure 2.

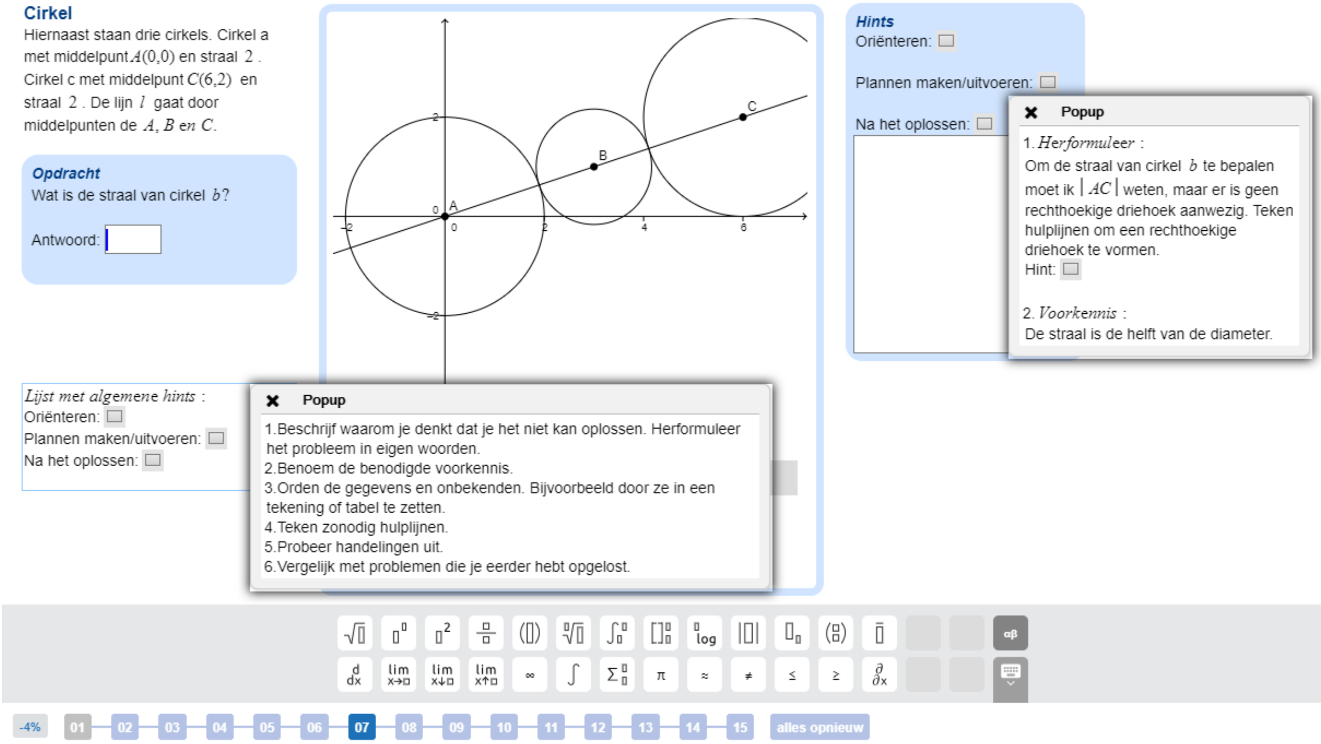

Figure 2. An example of a problem of the second level.

Firstly, we aimed to increase students' motivation towards the online lesson. The pilot study indicated that students' motivation dropped because of the difficulty of the problems. We tried to tackle this matter by offering students the possibility to work on their own capability. Easier problems were added, so there are three levels of difficulty in the program: easy, average, and hard. By implementing this change students will feel more challenged and confident in solving mathematical problems.

Secondly, we optimized the online lesson in terms of navigation. We structured the heuristics by the phases of problem solving. We started with the phases of problem solving according to literature and combined them into three phases: 'orienting', 'planning and executing' and 'after solving'. We combined 'make a plan and execute it', because here we can put all our mathematical hints, which makes it easier for students to navigate. Because students can determine with the help of the help-seeking model in which phase of problem solving they are, they can determine with more ease which help they need. This makes navigating easier. Thereby we tried to enhance the navigation by splitting up the heuristics and specific hints. By using the help-seeking model students can decide if and when they need heuristics or specific hints.

Finally, we optimized the online lesson in terms of self-regulation. Mostly the help-seeking model improves self-regulation, but the online lesson also gives attention to self-regulation. Self-evaluation is part of self-regulation (Zimmerman, 2002). We implemented self-evaluation by means of a textbox in the problem-solving phase 'after solving' in which students can evaluate their problem-solving process, progress or development.

To guide students to use the offered help effectively, we converted and expanded the help-seeking model of Roll (2007), see Figure 3. The three phases of problem solving 'orienting', 'making and executing plans' and 'after solving' are included in our help-seeking model, see Figure 4. Besides, the model is based on the phases of help-seeking. Each phase has a different color in order to keep them clearly separated. The model is structured from left to right because students are used to writing and reading from left to right.

In addition, this model helps students to plan well, to monitor their own behavior and to determine the approach to achieve the goal, which are part of self-regulation. It also gives students the possibility to evaluate their problem-solving process.

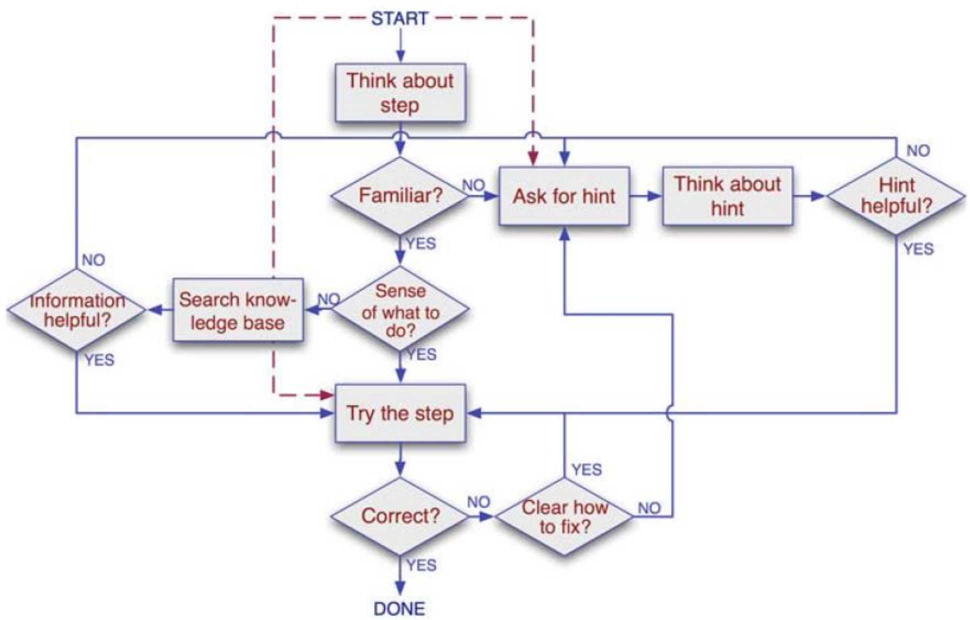

Figure 3. Adapted help-seeking model. Reprinted from 'Designing for metacognition—Applying cognitive tutor principles to the tutoring of help seeking', by I. Roll, V. Aleven & B.M. Mclaren & K.R. Koedinger, 2007, *Metacognition and Learning, 2*(2-3), p. 129.

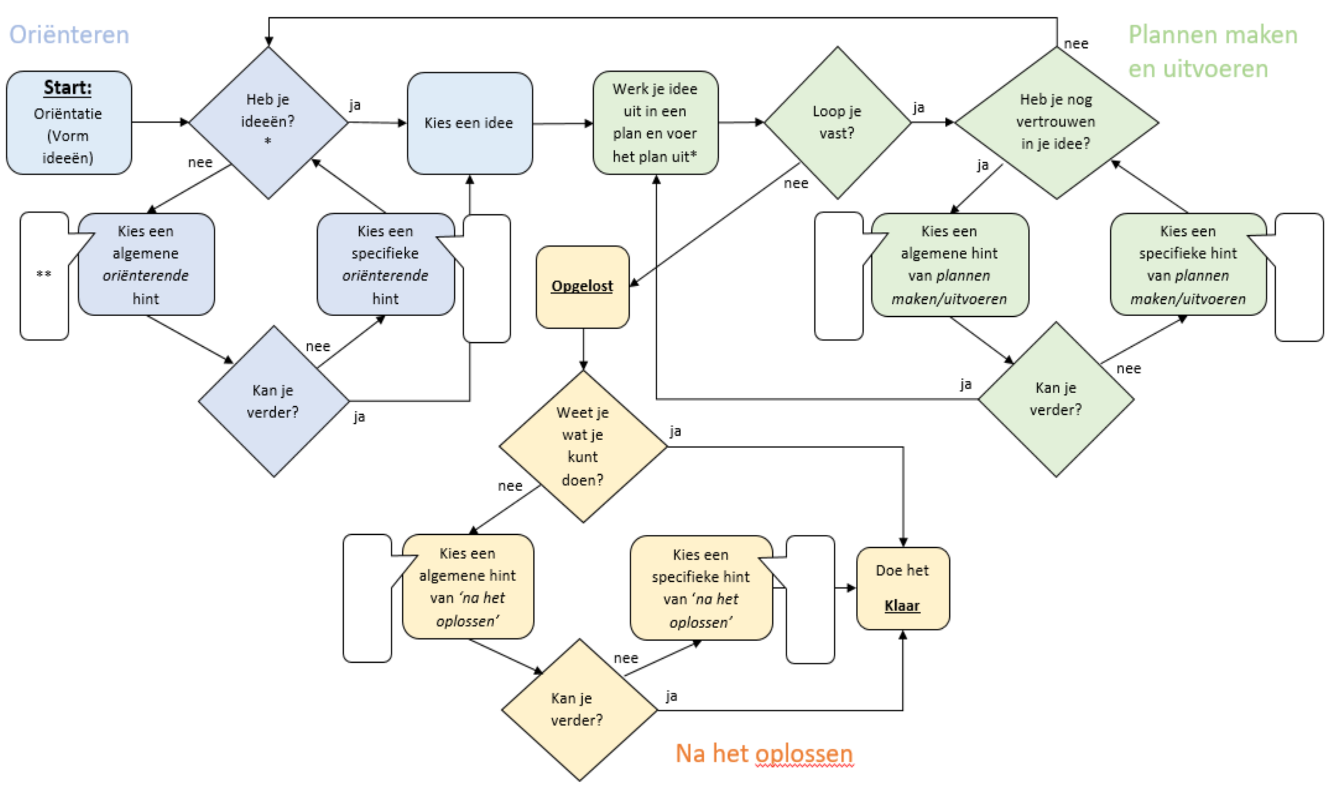

Figure 4. Our help-seeking model.

Improving domain knowledge

In mathematics it is important that students not only know procedures but that they can also construct concepts that they can manipulate. Gray and Tall (1994) define the term ‘procept’ as the combination of a process, object and symbol that is used to represent either the process or the object. The ability to deal flexibly with this ambiguous symbolism is the basis of successful mathematical thinking. The shift from a procedure to a process is known as compression of knowledge. This shift consists of different parts: “pre-procedure, a single step-by-step procedure, more than one procedure, seeing the process as a whole and conceiving the process as a thinkable concept (procept) that may be manipulated” (Tall 2006; p. 9), see Figure 5. We wonder whether compression can be stimulated through an intervention.

We interpret heuristics as compressed statements about strategy or mathematics, which is a new point of view. Hints are clues at the procedural level, while heuristics are more at the process and procept level. Schoenfeld (1985) stated: “Many heuristic labels subsume half a dozen strategies or more. Each of these more precisely defined strategies needs to be fully explicated before it can be used reliably by students” (p. 73). The compressed statements can be unpacked via the heuristic trees, which we call decompression. The hypothesis is that by making this decompression optional through heuristic trees for the students, a fading effect can arise: at some point, students no longer need the decompression because the compressed form has become manageable.

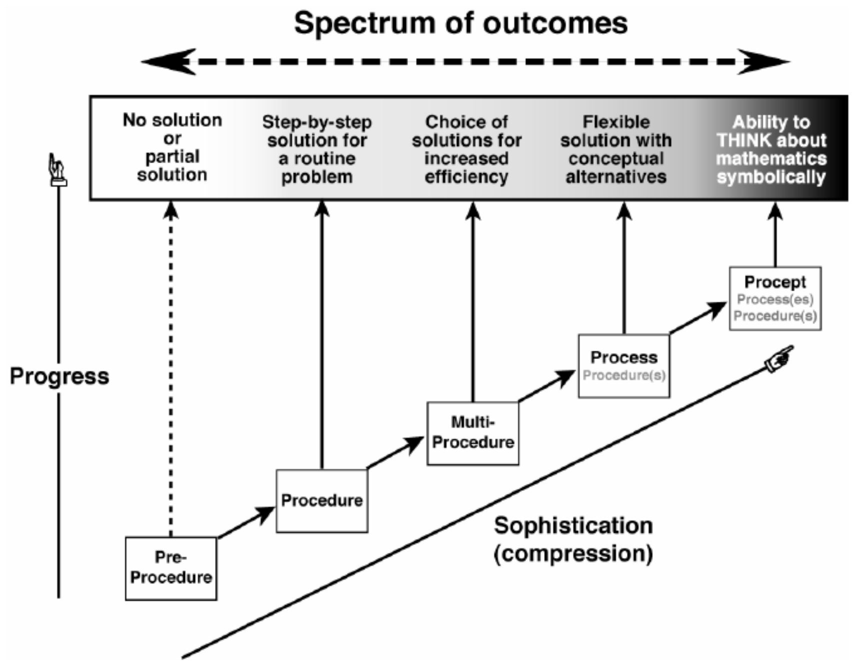

Figure 5. Compression of knowledge. Reprinted from '*Encouraging mathematical thinking that has both power and simplicity'* (p. 8) by D. Tall, 2006. Paper presented at the APEC-Tsukuba International Conference, JICA Institute for International Cooperation, Ichigaya, Tokyo.

Research question

Several studies have been carried out regarding improving self-regulation and help-seeking behavior, but there is no research that investigates whether correct use of heuristic trees influences students' use of heuristics and help-seeking behavior. In this study a help-seeking model and heuristics trees are offered to students to structure their problem solving. This study aims to investigate whether students change their problem-solving behavior with the help of a help-seeking model during a course that gives students the opportunity to work on mathematical problems with help use of heuristic trees. This leads to the research question: How does a course that uses heuristic trees in combination with a help-seeking model influence students' use of heuristics and help-seeking behavior? Moreover, we would like to know whether the use of heuristic trees can support compression of mathematical knowledge and knowledge of how to decompress heuristic support.

In order to answer the research question three sub-questions are formulated:

1. In what ways do the heuristics and the help-seeking model stimulate students in resolving mathematical problems independently without teacher support?
2. To what extent do students change their mathematical problem-solving behavior?
3. How does mathematical compression take place during the course?

Methods

For this design-based study a mixed-method approach was adopted to see if correct help use is changing students' use of heuristics and help-seeking behavior. A help-seeking model was constructed and a questionnaire with open-ended and closed-ended questions was conducted.

Setting

The online course for the students took place in a computer room at a secondary school. In the two 60-minutes lessons students worked in pairs on mathematical problems. At the start of the course we watched a video with the students in which the functioning of the online learning platform and the desired behavior was explained. Additionally, we told them that they had to fill in a help-seeking model worksheet while answering the problems. We explained to the students how the help-seeking model worked. Subsequently, each student had to fill in the first part of the questionnaire before they could start with the mathematical problems in pairs. One student was responsible for the computer and the other for the help-seeking model worksheet. At the end of the course, students filled in the second part of the questionnaire.

Participants

Fifty-three students took part in the online mathematics course. The participants consisted of students from 3 gymnasium (grade 9) and 5 VWO mathematics B (grade 11), specifically 24 to 29 students. The students ranged in age from 14 to 17. Forty-nine students completed the whole course. This represents a dropout rate of 8%. We received the help-seeking model worksheets from 23 pairs.

All participants had sufficient prior knowledge regarding the Pythagorean Theorem since it is part of the second year of secondary education. Both classes are not very experienced in mathematical problem solving, although students from the third grade are more skilled due to differences in teaching styles.

Students had to work in pairs on the online mathematical problems because it was established during the pilot that students naturally like to work together on digital problems. The questionnaire required many tasks to be executed simultaneously which was more feasible if the students could split these tasks. Besides, pairing up makes students more intelligent learners and more active (Segal, Chipman & Glaser, 2014).

Instruments

First, the online lesson was changed in terms of self-regulation, motivation and navigation. Secondly, the help-seeking model of Roll (2007) was adapted such that students could work with it. Thirdly, a questionnaire was designed to research the online lesson.

Help-seeking model

Students had to keep track of the help-seeking model worksheets, so the researchers could follow how they used the offered help. Students had to draw lines to see which pathway they followed and had to write down the applied hints and heuristics to see from which phase they used help.

Online learning platform

This study utilized an online learning platform where students need to solve 13 mathematical problems about the Pythagorean Theorem. An example of a problem is shown in Figure 2. This online lesson offers students the opportunity to decide for themselves which problem they want to solve. Students can write down their answers and they will see if they get it right or wrong. Additionally, students can write down things that they did after solving the problem in the textbox called ‘after solving’.

Questionnaire

A questionnaire with both open-ended and closed-ended questions was composed to measure to what extent students modify their problem-solving approach, what they thought about the help-seeking model, the heuristics and hints, the online lesson, and their knowledge about Pythagoras. Closed-ended questions were used to check the answers of the open-ended questions. A 5-point Likert scale was used for the questionnaire. The questionnaire is added in the appendix.

Data collection

The researchers of this study performed a classroom observation during the course. We looked at the students' behavior towards each other, the teacher, the program and the help-seeking model worksheets. Questionnaires and help-seeking models worksheets were collected. Students had to fill in a questionnaire before the start of the course and after the end of the course. In this study paper questionnaires were chosen over web-based questionnaires due to higher response rates (Ebert, Huibers, B. Christensen & M. Christensen, 2018). Students had to keep track of the help-seeking model worksheets while solving the problems, navigate through the hints on the computer and write down what they did after solving the problem. After the course we checked the online learning platform for answers, the text box 'after solving' and the use of certain hints.

Data analysis

The researchers of this study were present during the lessons and observed the students who were trying to solve the problems. They paid attention to the use of the help-seeking model, the hints and heuristics, and students' interaction with the teacher and each other.

The help-seeking model worksheets from students were compared with the data from the online learning platform. We checked whether the help-seeking behavior in the models corresponded to the help-seeking behavior from the data of the online learning platform. The worksheets were also checked to see if they were used properly and to see which and how many hints and heuristics from which phases and which level were used. We calculated percentages to see if there were differences between levels, phases and hints and heuristics. Besides, checking the online learning platform whether the questions were filled in, to assess the correctness of the answers and to see what student did after solving the problem, was also done manually.

The qualitative and quantitative data from the questionnaires is both evaluated individually and compared to each other. Specifically, percentages were calculated from the quantitative data to see how students self-reported their change in problem solving due to the course, their knowledge about Pythagoras, what they thought about the help-seeking model and the use of heuristics and hints. The qualitative data was analyzed to support these percentages. Additionally, students gave feedback about the online lessons.

The help-abuse of the hints and heuristics was also determined. The help-seeking model worksheets and the online learning platform were analyzed to check if help-abuse occurs in the form of having a wrong answer and not asking for help. The second form of help-abuse that we looked for were pairs who solved less than seven problems (so they are not proficient problem solvers), but used the available support in less than half of their attempts. The last form of help-abuse is using all heuristics and specific hints from minimal two phases and having a correct answer. The frequency of help-abuse is measured.

To determine compression of knowledge about the Pythagorean Theorem, the relative depth of the heuristic trees about Pythagoras was determined. The use of specific hints about the Pythagorean Theorem was compared within pairs and problems. We checked if students completed at least three problems where they used specific orienting and planning hints about Pythagoras.

Results

Help-seeking models and the online learning platform

Problems

Students had the possibility to address 13 problems. A total of 23 pairs filled in the worksheets. The mathematical problems are subdivided into three categories ascending in difficulty: level one (problems one to three), level two (problems four to seven) and level three (problems eight to 13). The number of pairs that solved a particular problem is shown in Figure 6. All level one problems were solved 100% correct. From level two this percentage was 91% and from level three it was 89%.

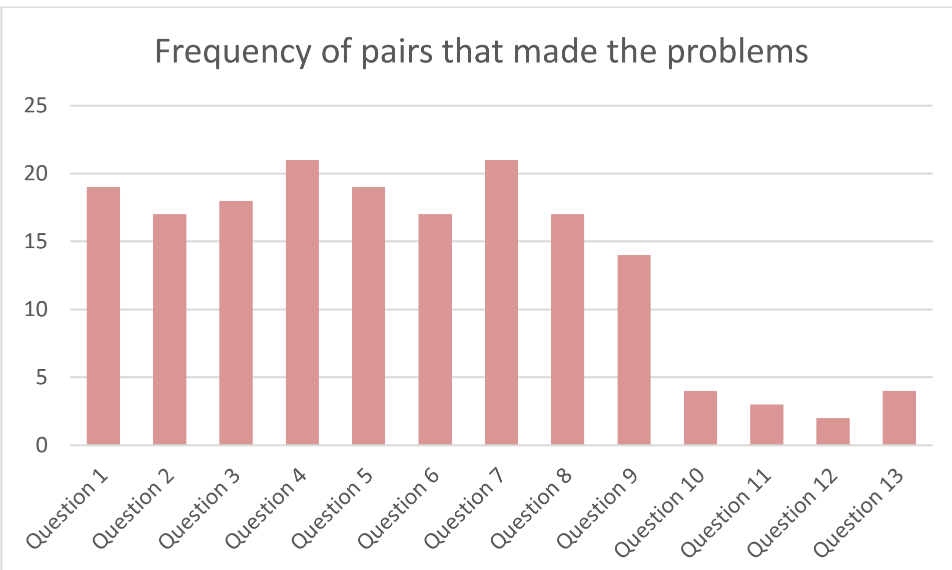

Figure 6. Frequency of the addressed problems.

Use of heuristics

The given hints were subdivided into heuristics and specific hints. The use of heuristics and the use of specific hints by pairs is displayed in Figure 8 and Figure 7 respectively.

The use of specific orienting hints is absent in level one but increases from level two to three. The use of specific planning hints increases from level one to two, but decreases from level two to three. Additionally, the specific hints after solving are only used in level one.

The use of orienting heuristics increases from level one to two, but decreases from level two to three. Finally, the use of planning hints increases from one up until level three and the use of heuristics after solving increases from one to two, but is absent in level three.

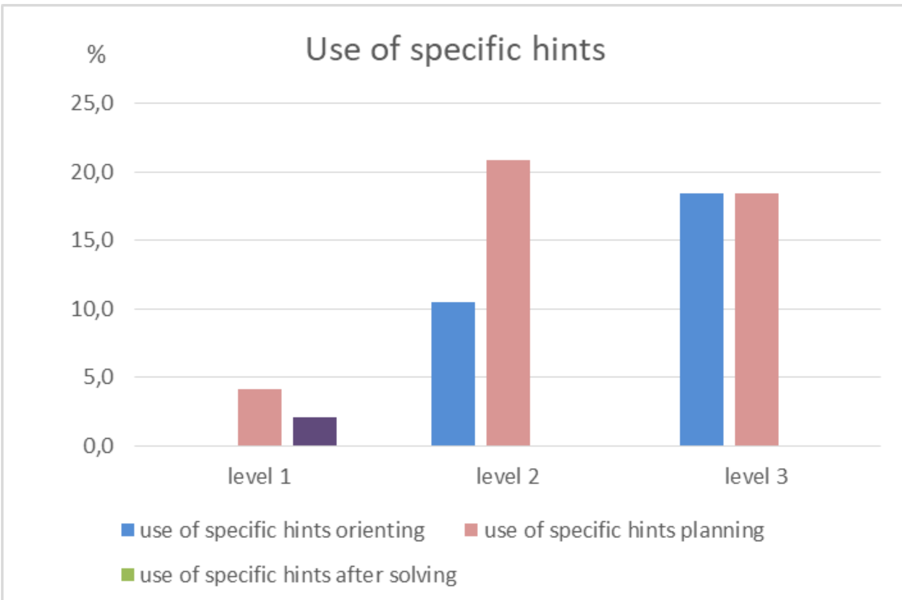

Figure 7. The use of orienting, planning and after solving specific hints by pairs for each level.

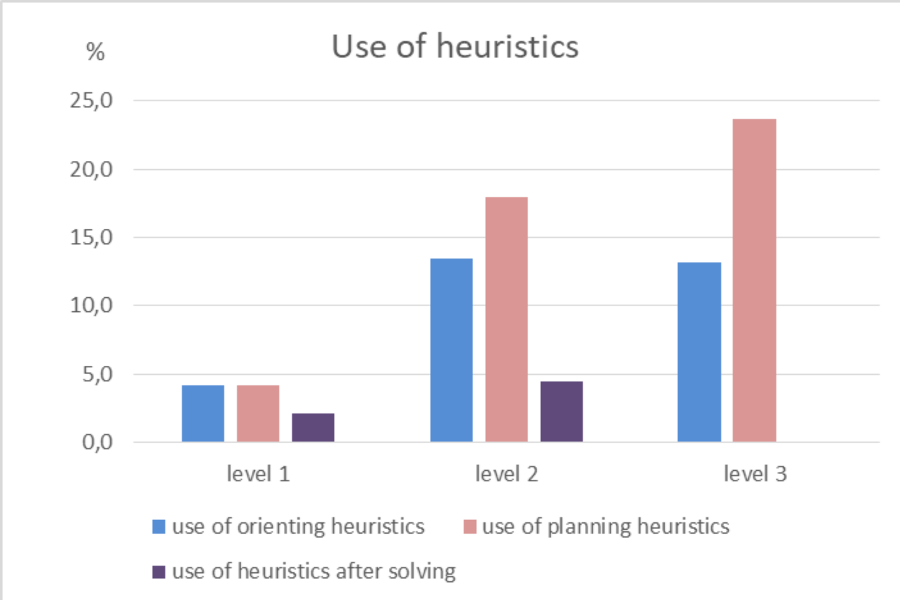

Figure 8. The use of orienting, planning and after solving heuristics by pairs for each level.

Help-seeking

Students could ask for help in three phases; orienting, planning and executing and after solving the problem. Figure 9 shows the proportion of students that seek help in each level in the form of percentages. In level one 83% of the students did not look for help, against 17% of the students that did look for help. In level two 60% of the students did not look for help, against 40% of the students that did look for help. In level three 47% did not look for help, against 53% that did look for help.

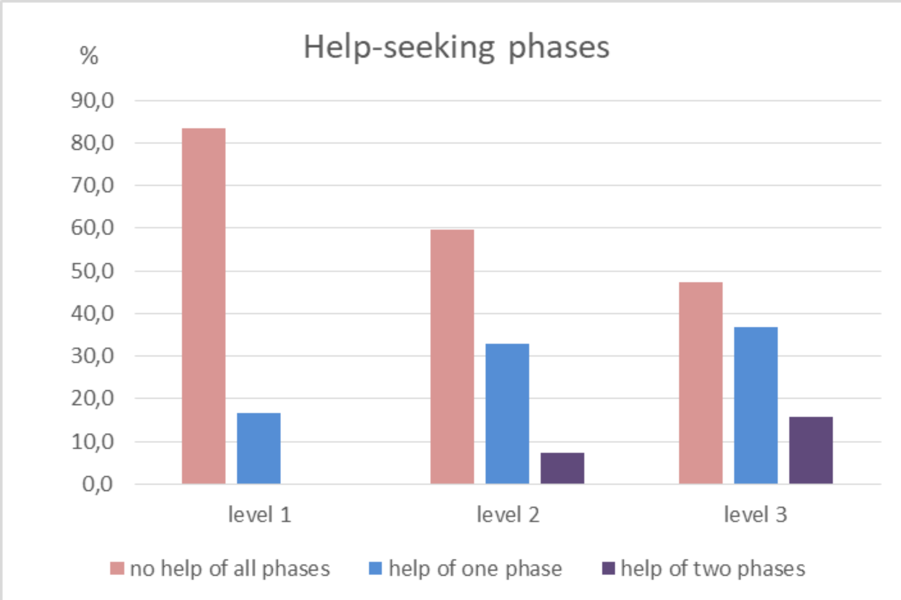

Figure 9. The search for help for each level.

Incorrect use of help-seeking model

Students filled in 153 help-seeking model worksheets in total. From those models 76% was used correctly, against 24% that was used incorrectly. Students used the models incorrectly by only marking in that they used heuristics (11%), while they should also have marked in specific hints. Additionally, students only marked in specific hints, while they should also have marked in heuristics (31%). Besides, they did not mark in any help use, while they should have marked in hints and heuristics (42%). Finally, 17% of the students did not fill in the help-seeking model worksheet, while answering the problem.

Help-abuse

The first form of help-abuse is defined as having a wrong answer and not asking for help. This occurred in one help-seeking model worksheet. The second form of help-abuse that we looked for is pairs who solved less than seven problems (so they are not proficient problem solvers), but used the available support in less than half of their attempts. This behavior was found in three pairs. The last form of help-abuse is using all heuristics and specific hints from a minimum of two phases and having a correct answer. This form of help-abuse did not occur in any worksheet.

After solving the problem

After solving the problems students should fill in the textbox 'after solving'. What students should fill in, is displayed in Table 1. It was found that things that students do after completion can be categorized into six categories (see Figure 10). Most of the students did nothing afterwards, while the rest of them tried to describe the method, process, or strategy, attempted to find more solutions, and checked their answers.

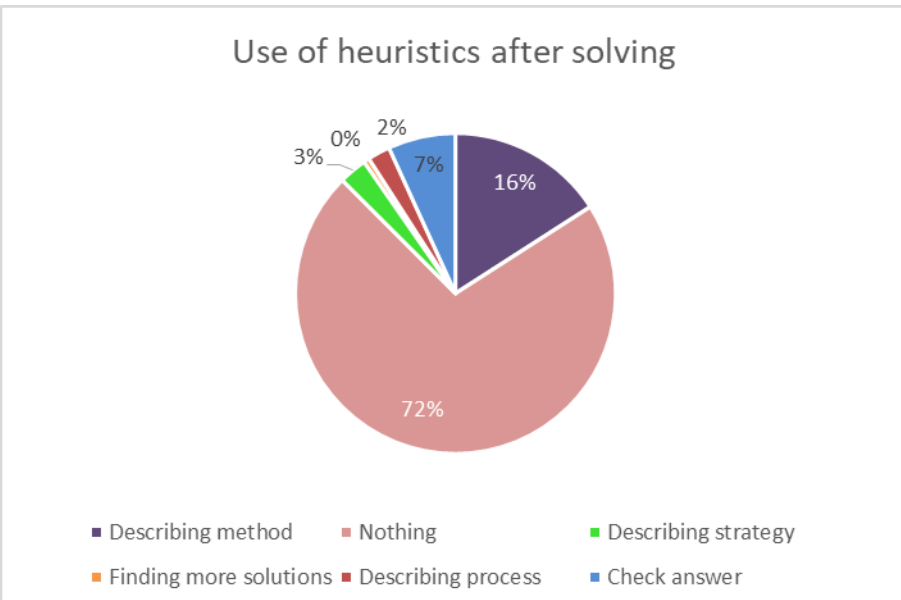

Figure 10. The different kinds of used heuristics after solving the problem.

Questionnaire

Closed ended questions

About 47% of the students agreed or totally agreed with the statement that the help-seeking model and the hints helped them in solving problems, whereas 22% of them disagreed or totally disagreed with this statement (see Figure 11). Furthermore, 37% of the students agreed or totally agreed with the statement that they liked working with the help-seeking model and the hints on the computer, but 35% of them disagreed or totally disagreed with this statement (see Figure 12).

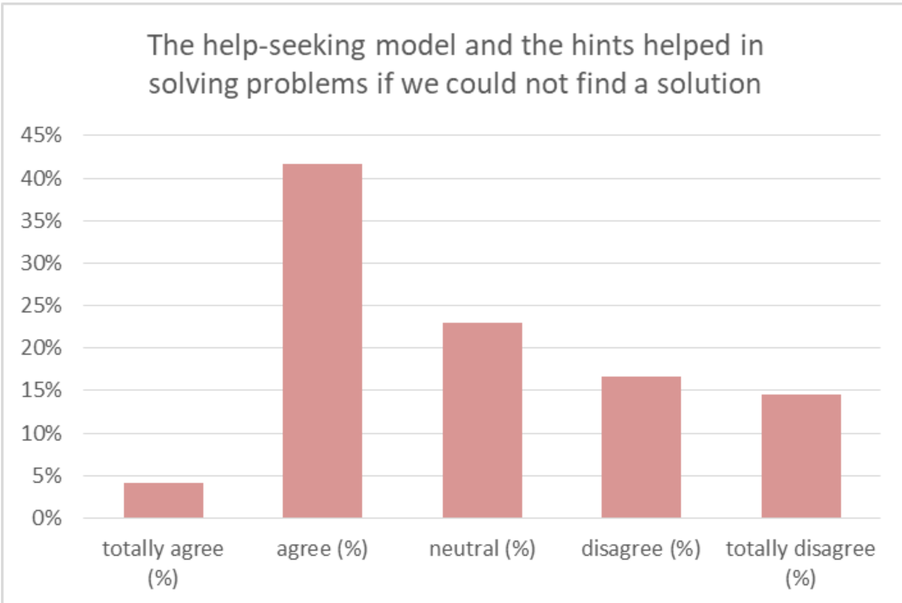

Figure 11. Students' level of agreement with the statement that the help-seeking model and the hints helped them in solving problems they could not solve.

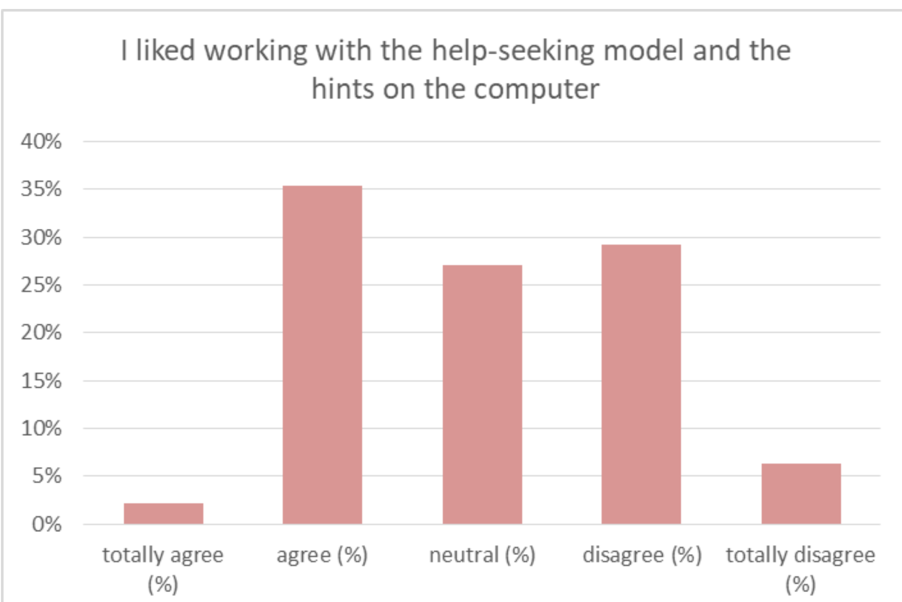

Figure 12. Students' level of agreement with the statement that they liked working with the help-seeking model and the hints on the computer.

About 31% of the students agreed or totally agreed with the statement that they can now use heuristics for solving mathematical problems, whereas 33% of them disagreed or totally disagreed with this statement (see Figure 13).

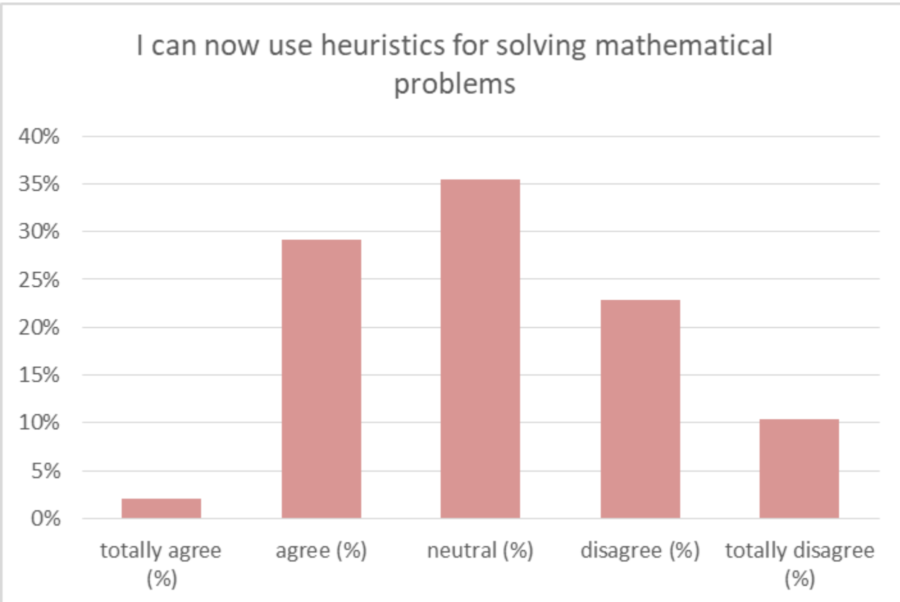

Figure 13. Students' level of agreement with the statement that they now can use heuristics for solving mathematical problems.

About 21% of the students agreed or totally agreed with the statement that the way they approach mathematical problems has changed, whereas 39% of them disagreed or totally disagreed with this statement (see Figure 14). Furthermore, 48% of the students agreed or totally agreed with the statement that they now know more about the Pythagorean Theorem, but 29% of them disagreed or totally disagreed with this statement (see Figure 15).

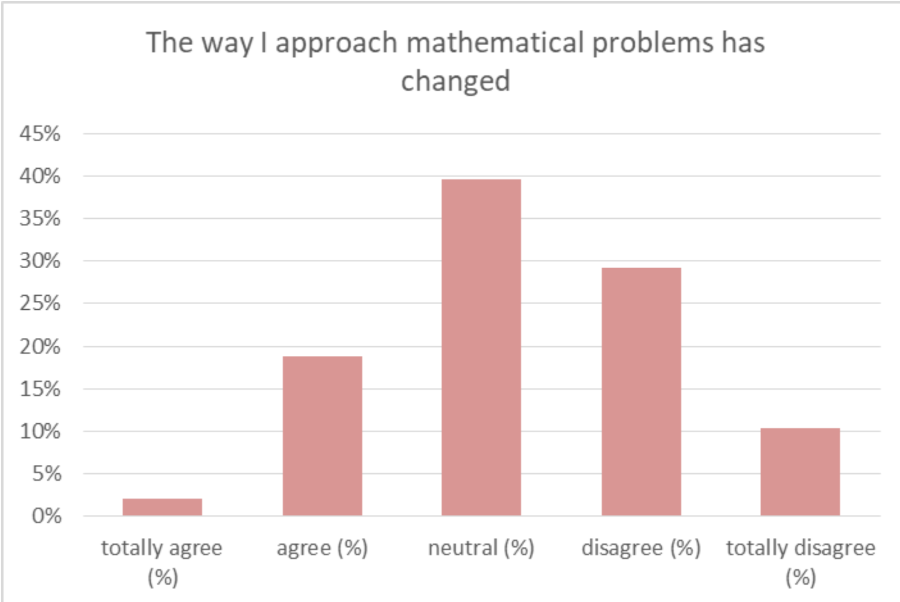

Figure 14. Students' level of agreement with the statement that they now have changed their approach to mathematical problems.

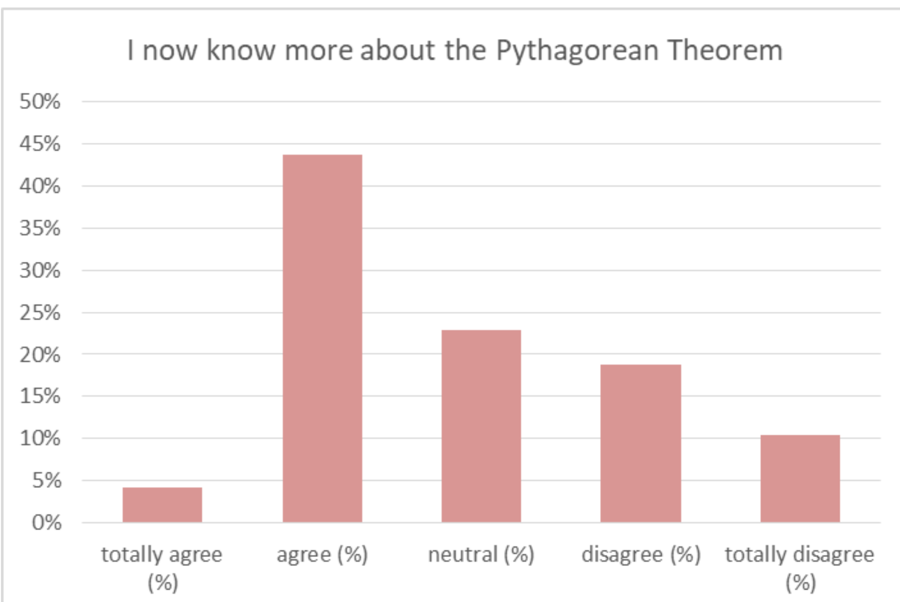

Figure 15. Students' level of agreement with the statement that they now know more about the Pythagorean Theorem.

Open ended questions

Thirty-four students indicated by means of self-report that they have changed their approach to solve problems (71%), against 14 students that have not changed their approach to solve problems (29%). Some similar answers were mentioned by students who have changed their approach. Six students reported that they will work more systematically (13%), five students will check their answer (10%) and five students will look for more methods to find the answer (11%).

Fifteen students indicated that the help-seeking model had no influence on the choice to use hints, compared to seventeen students who indicated that it did have an influence. From all participants, 22 students supported this statement with an argument. The arguments regarding why the help-seeking model did not have any influence are presented in Table 2. The arguments why the model did have influence are shown in Table 3.

Table 2. The help-seeking model did not have any influence.

Argument	*Frequency*
The use of hints was embarrassing	1
Hints were used without the help-seeking model	1
The help-seeking model did not work	1
Did not want to use any hints	1
Did not need any hints	1

Table 3. The help-seeking model did have an influence.

Argument	*Frequency*
Helped with more systematic solving	2
The hints were used earlier	1
It was easier to determine which hints you needed	2
You went through the hints more slowly	1
The help-seeking model was used as additional help	1
Otherwise only specific hint were used	1
Otherwise no hints were used	3
The help-seeking model delayed the use of hints	1
The help-seeking model was only used when you got stuck	4
Not always when it had to be used	1

Feedback about the lesson, the help-seeking model and the heuristics and hints on the computer was given by 35 students. These feedback items are presented in Table 4, Table 5 and Table 6 respectively. Additionally, three students indicated that the phase 'after solving' was unclear and unnecessary. They did not know what to do after solving the problem.

Table 4. Feedback about the online lesson.

Feedback lesson	*Frequency*
I like the lesson very much	6
The lesson contained variation	1
It helps you with systematic solving	3
Problems were good with increasing difficulty	2

A problem can take a long time	2
Make problems about other mathematical subjects	1
Explanation at the start of the lesson could be clearer	1
Titles in the online lesson could be clearer	1
The online lesson would be helpful for students who have difficulties with problem solving and reasoning step by step	1
The online lesson helps with solving in steps	2
Include calculation errors	3
Correctly display the figures	2

Table 5. Feedback about the help-seeking model.

Feedback help-seeking model	*Frequency*
The hints in combination with the help-seeking model were clear	8
Clear	2
Clear because of the use of color	1
It gave structure to solving	1
It helped with planning	1
It shows the thinking-process well, which normally goes unconsciously	1
All possible strategies were an element of the model	1
Handy when you are stuck	2
You have an idea how far in the process of solving you are	1

It helped with solving (in steps)	2
Unclear	3
Too much work	3
Not handy to often go back to the model	2
Unclear because the arrows in the model are intertwined	1
Sometimes unnecessary	1
Not very useful	1
Not nice to work with	1

Table 6. Feedback about the hints and heuristics.

Feedback hints and heuristics	*Frequency*
The hints in combination with the help-seeking model were clear	8
Handy when you begin with a problem	1
Handy when you are stuck	2
There is just enough help to continue with the problems	1
They were clear	3
They were unclear	2
There are many pop-ups when using help	1
You do not always get the answers to your question	1
Sometimes you get information that you already had thought of	1
The heuristics were irrelevant	2
The general orientation is unnecessary	2

Observations

Students discussed the problems in pairs. There was only interaction between students and the teacher about practical matters. The students only asked a few questions and were working without interruptions. We saw students drawing lines and noting hints when they were solving the problems. Students asked us if they could not do this more often in math lessons and if they could continue with the problems at home. Nevertheless, we were forced to intervene after the first lesson. We had to point out to students that they had to fill in the models and solve the problems simultaneously. Besides, just before the start of the lessons, we discovered that a question in the questionnaire was missing. When we found that out, we wrote the missing question on the board in order to still get all the answers.

Conclusion and discussion

In this section the following research question will be answered: How does a course that uses heuristic trees in combination with a help-seeking model influence students' use of heuristics and help-seeking behavior? In general, we can conclude that the heuristic trees in combination with the help-seeking model led to close to no help abuse. The absence of help abuse indicates good help-seeking behavior that led, in combination with the hints and heuristics, to a high solving rate. Additionally, students sought for more help when the difficulty of the problems increased. This will be further elaborated below.

The answer to the first sub-question "in what ways do the heuristics and the help-seeking model stimulate students in resolving mathematical problems independently without teacher support" is as following: the help-seeking model and the hints helped in resolving mathematical problems in a structural and independent way. The answer to the second sub-question "to what extent do students change their mathematical problem-solving behavior" is as follows: at least 21% and a maximum of 71% did change their approach to solve mathematical problems. Unfortunately our attempts to measure compression of knowledge, which is part of the third sub-question, did not succeed.

This section starts with an explanation of the findings, generalizations of the lesson, limitations and ends with implications for further research.

Experience lesson

During the two lessons of 60 minutes, students were working in pairs on the mathematical problems while discussing it. They were calm and did not interrupt their activities. The students solved many problems in the given time. These are the indicators that students were working with concentration and enthusiasm. Besides, we saw them drawing lines and noting hints, so they were actively using the help-seeking model during the lessons.

Use of hints and heuristics

Based on Figure 7, Figure 8 and Figure 9 we conclude that students are seeking more help when the difficulty of the problems increases.

The use of orienting heuristics is increasing from level one to level two, but a small decrease is found from level two to three. In level two students need more time for orientation because the problems demand more insight and skills. This is probably the reason for the increasing use from level one to level two. The decrease from level two to three could be a result of students becoming familiar with the concept such that they know which heuristics they find relevant. However, students can also feel like the use of orienting heuristics becomes unnecessary. The use of specific orienting hints does increase from level one up until level three as a result of increasing difficulty. Students know which heuristic they need to use, but when the problems become more difficult, they do not know how to use the heuristics anymore.

An increase in the use of planning heuristics from level one up until level three is present. Due to the increasing difficulty, students probably do not know which problem-solving method they can use. The heuristics direct the students to the right mathematical method. The use of specific planning hints is increasing from level one to two because the mathematical problem-solving skills of some students are not sufficient to solve level two problems by themselves. From level two to three, the use of specific planning hints is decreasing. Only students who possess better mathematical problem-solving skills reached level three, which could explain the decrease in the use of specific planning hints.

Heuristics after solving the problem were used very little in level one and a small increase in the use of heuristics after solving was present from level one to two. Specific hints after solving were barely used in level one and were not used at all in level two and three. Students probably did not know exactly what was expected from them and therefore skipped this phase. Out of curiosity they might have taken a peek at the hints in level one.

Help-seeking model

We conclude that the specific hints were clear to students because the researchers observed that students were asking almost no questions, but the solving rate in every level was high. Most of the help-seeking model worksheets were filled in correctly and the solving rate for each level was high. Additionally, many students thought that the help-seeking model and the hints helped to solve problems when they could not find a solution by themselves (see Figure 11). Observed was also that students were using the help-seeking models when solving the problems, so they followed a certain pathway that led to correct answers. Subsequently, we conclude that the help-seeking model and the hints helped in resolving mathematical problems in a structural way.

There are several issues under discussion regarding the help-seeking model. Firstly, not all students filled in the model while solving the problems, but they filled in the model after they had finished the problems. We tried to prevent this, but it was hard to keep an eye on all students at the same time. This could result in students looking for help in another way than the help-seeking model intended. In addition, it was unclear if students really wrote down all the help they used. Students were not only asking for help in the online program, but also reached out to teachers, fellow students and the internet for help. It may therefore be that they requested and noted fewer hints than they actually needed. Additionally, students told us during the lesson and on paper that they did not want to use any hints because they wanted to find the answer by themselves. It could be that students used hints and did not write that down because they did not want to use it. It is not possible to check the use of all the hints in the online learning platform, so it could be that students used more hints than we know.

We noticed several forms of help abuse regarding the help-seeking model worksheets, but most were marked in correctly. Some students did not write down the hints and heuristics they used or they did not follow the model properly, meaning that they did not use all the hints and heuristics that they had to use. Probably the best explanation for these forms of abuse is that students found it too much work to execute each step of the model.

Help-abuse

In the help-seeking model worksheets we did not find much help-abuse. It was not noticed that students clicked on all hints to find the correct answer soon. It was seen once, that students were not asking for help even though they had a wrong answer, and in three pairs it was observed that students did not solve many problems while they did not ask for help frequently. A total of 153 schemes were filled in by 23 pairs, so we can conclude from this that the occurrence of help-abuse is negligible. This statement indicates that most students sought for help in a good way.

In the first version of the online lesson, it was concluded that students either used no hints or used them all at once (Bos, 2017). In contrast to the initial findings, this version shows a negligible amount of help-abuse in the help-seeking model worksheets. The decrease of help-abuse is probably a result of the implementation of different levels of difficulty. If students start at their own level, they can get used to solve mathematical problems using hints and heuristics. As a result, students might need fewer hints in higher levels. Lesser occurrence of help-abuse is not only a result of the implementation of levels but might also be a result of the help-seeking model and of the structure of the hints. Compared to the Help Tutor of Roll (2006), there were

17% of the actions identified as help-seeking errors, while we observed close to no help-abuse. The threshold to determine how many times help-abuse occurred, was randomly chosen. However, a change in threshold would not make a big difference in the frequencies because close to no help-abuse is observed.

The most observed form of help-abuse in using hints was that students were not asking for help frequently and that they did not make many problems. A reason that students are not using help when they actually need it, is because students are avoiding cognitive overload (Aleven, 2003). Another reason could be that help-seeking thought to show incompetence (Butler, 1998). Additionally, by asking for help the students may think that they are seen as dumb (Newman and Goldin, 1990). In general, students that are more focused on learning than on performance are more likely to seek help (Ryan and Pintrich, 1997).

Problem solving

The results of the closed questions of questionnaire show that 21% of the students changed their approach to solve mathematical problems (see Figure 14). With the open-questions 71% of the students notated that they did change their problem-solving approach, against 29% that did not change their approach. We conclude from this that at least 21% and a maximum of 71% did change their approach to solve mathematical problems.

There were two questions about problem solving in the questionnaire. From the closed questions it came forward that more students thought that they did not change their approach in solving mathematical problems than students who thought they did. Noteworthy is the fact that in the open question the majority said that they did change their approach to solve problems. An explanation can be that in the open questions students had to come up with examples and started thinking more about what they might have learned. Minor changes in the behavior of approaching a mathematical problem were not seen as changes in the closed questions.

After solving

Hints and heuristics of the phase after solving the problem were not frequently used by the students that made the problems (heuristics; level 1: 2%, level 2: 5% level 3: 0% and specific hints; level 1: 2%, level 2: 0% and level 3: 0%). Besides, 72% of the students did not fill in the textbox 'after solving'. However, when the textbox was filled in, something useful was done in 13% of the cases. To conclude, there was a limited and incorrect use of the textbox. On the other hand, the correct use of the textbox was achieved among some of the students.

It is noteworthy that in only 27% percent of the cases, students filled in the textbox 'after solving'. In the video tutorial we showed that answers should be checked. However, this message was not clear enough since the majority did not check their answer. On top of that, the students indicated that they did not know what was expected of them after solving the problem. From the students who filled in the textbox, the majority described the method and not the strategy. This suggests either that the students did not know the difference between a method and strategy or that the students did not know that it was expected of them to fill in the strategy and not the method.

Limitations

One of the goals for this research is to determine to what extent students change their mathematical problem-solving behavior. From the open-ended and closed-ended question we got positive results, but we were unable to give an exact answer to this sub-question. The study will benefit from more precise measurement with interviews and a pre- and posttest.

Students misunderstood some questions in the questionnaire because the questions were probably too difficult or not clear enough. It would have been better to conduct interviews, because it allows us to explain the question and to make sure that the students understand the question completely. An interview also offers the possibility to ask for elaboration and clarification.

In the questionnaire we asked questions about both the help-seeking model and the hints. Because we did not separate these two, we could not make distinct conclusions. It would have been better to ask questions about the help-seeking model and hints separately.

Unfortunately we cannot say if mathematical compression took place during the course, which was a goal of this study, because we did not get the right data. We did not have any groups that had used specific orienting and planning hints about Pythagoras in minimal three problems. Therefore, we cannot conclude if compression about the Pythagorean Theorem has occurred.

Generalizations

We think that the outcomes of this study are not only applicable to the subject Pythagorean Theorem, but to all mathematical subjects. The reason for this statement is that heuristics can be used to solve mathematical problems in general. Also the specific hints can be adjusted with the same structure to support other mathematical subjects.

The outcomes of this study can be generalized to other schools, years and students of almost the same level because this online lesson is teacher independent. Students are required to have some prior knowledge about the Pythagorean Theorem. The difference between younger and older students will probably be that older students make more problems because it is proven that students improve with help-seeking with age (Newman & Schwager, 1995) because their monitor and reflecting skills on their performances is increasing with age (Ryan & Pintrich, 1998). However, the results will not be generalizable for other school levels because the eagerness and independence will probably be less.

Recommendations

Recommendations about the design of this study, the lesson and future research will be discussed in this section.

Design

At the beginning of the lesson, we showed students a video about the expected behavior. This video, nevertheless, did not give a clear picture of how students should use the help-seeking model worksheet. It is important that students can see how they have to fill in the model while making the problems. Also, the help-seeking model should be adapted, because the model misses a branch. After choosing a specific hint from making plans and execute them, there should come a box with 'try your approach' that leads to the box 'are you stuck?'. Additionally, it should be considered if it is possible for students to use the help-seeking model worksheet only when they get stuck, because several students indicated that it was a lot of work to constantly fill in the help-seeking model worksheet. In other words, they only learn to seek help when they do not know what to do. The last recommendation about the design is that the images should be the same for every version of the online platform. Based on our experience, the image differs within the versions, which makes it confusing for students.

Lesson

Next time it would be an idea to discuss the heuristics in class and to explain clearly what we expect from the students concerning the textbox 'after solving', because then we can point out that it is important to understand the heuristics and to fill in this textbox. Additionally, it is meaningful to emphasize that the students do not have to start with the first problem. We namely noticed that most students made the assignments horizontally. However, they can decide for themselves with which level they want to start. In addition, it is recommended that students can work thrice 60 minutes instead of two times 60 minutes, such that they can make more problems.

Research

In future research it needs to be investigated how students change their problem-solving behavior exactly. This can be done with a pre- and posttest in which students have to solve a problem individually. Furthermore, interviews should be conducted to elaborate more on the different issues. Besides, there can be investigated if mathematical compression takes place while working with the heuristic trees. It would be nice to test the hypothesis that compression occurs when the relative depth of using a heuristic tree decreases over time would result in a relevant outcome. Moreover, we saw in this study that the use of planning heuristics decreases from level two to three. It will be interesting to examine if this is caused by compression or by the fact that students think the heuristics are not useful. Besides, it can be tested if the students really internalized the heuristics.

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Appendix

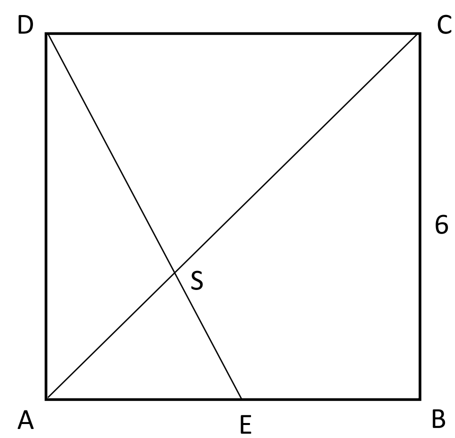
Hallo,

Bedankt voor je deelname aan dit onderzoek. Deze vragenlijst zal ongeveer 10 minuten duren. Er zal vertrouwelijk met je gegevens worden omgegaan. Het is belangrijk dat je de vragenlijst goed invult, neem dus de tijd. Geef je antwoord op basis van je eigen ervaringen. Voel je vrij om dit naar waarheid in te vullen: de gegevens worden anoniem verwerkt.

Groetjes,
Rona Lemmink

Vooraf:

1. *Hiernaast zie je vierkant ABCD. AE is de helft van AB. Bereken exact de afstand DS.*



a) *Beschrijf het proces van oplossen. Welke stappen heb je gemaakt?*

----

b) *Had je behoefte aan hulp, en zo ja, heb je daar toen om gevraagd?*

----

c) *Kon je iets met de hints?*

----

2. *Kan je voorbeelden noemen waarvoor je de stelling van Pythagoras kunt gebruiken?*

Na afloop:

1. *Wat is er na aanleiding van deze lessen veranderd in de manier waarop je een wiskundig probleem aanpakt?*

----

2. *Wat vond je van het gebruik van het hulpzoekschema in combinatie met de hints? Geef hieronder 2 tops als je die hebt en geef 2 tips als je die hebt.*

Tops: 1.____
2.____

Tips: 1.____
2. ____

3. *Geef voorbeelden van hoe je een algemene hint kunt toepassen bij het oplossen van problemen. Gebruik de fasen: oriënteren, plannen maken/uitvoeren en na het oplossen.*

----

4. *Kan je voorbeelden noemen waarvoor je de stelling van Pythagoras kunt gebruiken?*

<u>Omcirkel het goede antwoord:</u>

1. *De manier waarop ik wiskundige problemen aanpak is veranderd.*

   1.Helemaal eens; 2. eens; 3. neutraal; 4. oneens; 5. helemaal oneens.

2. *Het hulpzoekschema en de hints hielpen bij het oplossen van problemen, als we er niet uitkwamen.*

   1.Helemaal eens; 2. eens; 3. neutraal; 4. oneens; 5. helemaal oneens.

3. *Ik vond het fijn om te werken met het hulpzoekschema en de hints op de computer.*

   1.Helemaal eens; 2. eens; 3. neutraal; 4. oneens; 5. helemaal oneens.

4. *Ik kan nu algemene hints gebruiken bij het oplossen van wiskundige problemen.*

   1.Helemaal eens; 2. eens; 3. neutraal; 4. oneens; 5. helemaal oneens.

5. *Ik weet nu meer over de stelling van Pythagoras.*

1.Helemaal eens; 2. eens; 3. neutraal; 4. oneens; 5. helemaal oneens.