Using domain-specific and generic knowledge to support discovery learning about geometrical optics in a computer-based simulation

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Introduction

In the context of the project 'Prior knowledge and discovery learning' (subsidized by NWO, the Dutch equivalent of ESF), a number of studies have been conducted. These studies aimed at clarifying some of the constraints of discovery learning in computer-based simulations. For this purpose, the studies focused on the method students from secondary school used to operate a computer simulation on the topic of geometrical optics. The computer simulation (called 'Optics') was designed to elicit scientific discovery learning behavior. The Optics simulation offers a versatile and dynamic learning environment, with built-in tools for the analysis of discovery learning processes. To study discovery learning processes, all actions that students performed in the Optics simulation were registered. Domain-specific knowledge and generic knowledge of mathematical relations were measured before students commenced work in the simulation. The earlier studies that we have carried out (reported in detail in Hulshof, 2001) show only a limited influence of the level of prior domain-specific knowledge, and a general effect of generic knowledge on discovery learning processes. Learning effects were minimal, which may have been caused by the lack of support students received during learning, in combination with the poor level of prior knowledge about geometrical optics that students possessed. In a first study (see Hulshof, De Jong, & Van Joolingen, 1999) we had already attempted to influence prior domain-specific knowledge about another simulation about a ficitious domain (called 'Bubbles'). It was found that only giving students knowledge about the domain prior to working with the simulation did not render discovery learning more effective. The objective of the present study was to render discovery learning in the Optics simulation effective, by manipulating knowledge *during* discovery learning. This way, knowledge was used as an active support measure. In the study, domain-specific and generic knowledge were available to a group of students while they were working with the Optics learning environment. Another group, who did not have this type of support available, served as a control group. It was expected that having knowledge available during discovery learning would affect the learning process and lead to more effective learning.

Theoretical framework

The theoretical framework that has been used for all the studies that were conducted in this research project is the SDDS model of discovery learning (Klahr and Dunbar, 1988; Klahr, 2000). During discovery learning with a computer simulation people carry out experiments in a virtual environment to get new information and to modify their existing beliefs (Kulkarni & Simon, 1990). When the process of experimentation and the process of deriving a hypothesis are described as search processes, Newell and Simon's

(1972) general theory of problem solving can be extended to incorporate both these processes. Klahr and Dunbar's SDDS model offers a description of discovery learning as a problem solving-like search through two problem spaces: *hypothesis space* and *experiment space*. The model states that discovery learning consists of three components: search hypothesis space, search (or: test) experiment space, and evaluate evidence. Each of these processes has its own goal. In hypothesis space search, the goal is to form a fully specified hypothesis. This hypothesis can be tested by performing an experiment. The resulting evidence is evaluated, the goal of which is accepting or rejecting a stated hypothesis. The SDDS , and the extensions that have been added to it by Van Joolingen and De Jong (1997)It can be used as a general framework for studies on discovery learning processes.

One goal in this research project has been to further extend the SDDS model, by focusing on the role of different types of knowledge on the search through hypothesis space and experiment space. Several studies (e.g., Glaser et al., 1992; Lavoie and Good, 1988; Njoo and De Jong, 1993) have shown that a relation between prior knowledge and discovery learning process and learning performance exists. In these studies, more domain-specific prior knowledge was shown to lead to more effective discovery learning behavior and higher learning effects. Our hypothesis is that knowledge will only lead to more effective discovery learning when it is available, or can be accessed, during learning. In the case of geometrical optics, students had trouble in accessing their knowledge about the subject during learning. In this study, it was attempted to influence this situation, by making knowledge available to students. The main research question of the current experiment was: what differences can be found between students who are not supported in their learning behavior, and students who have support available in the form of domain-specific and generic tips during discovery learning?

We expected differences between an experimental group (who had help available) and a control group (who had no help available) in scientific discovery learning processes and in performance on a domain-specific knowledge test. It was expected that the experimental group would benefit from having knowledge available, which should result in more progress from pretest to posttest on the domain-specific knowledge test.

Method

The subjects who participated in the study were 32 students who were following technical vocational education (mean age 19 years). All students worked for a set amount of time (about 60 minutes) with a version of the Optics computer simulation (see Figure 1). The simulation allows for the manipulation of light sources and lenses, and allows students to make both qualitative and quantitative measurements.

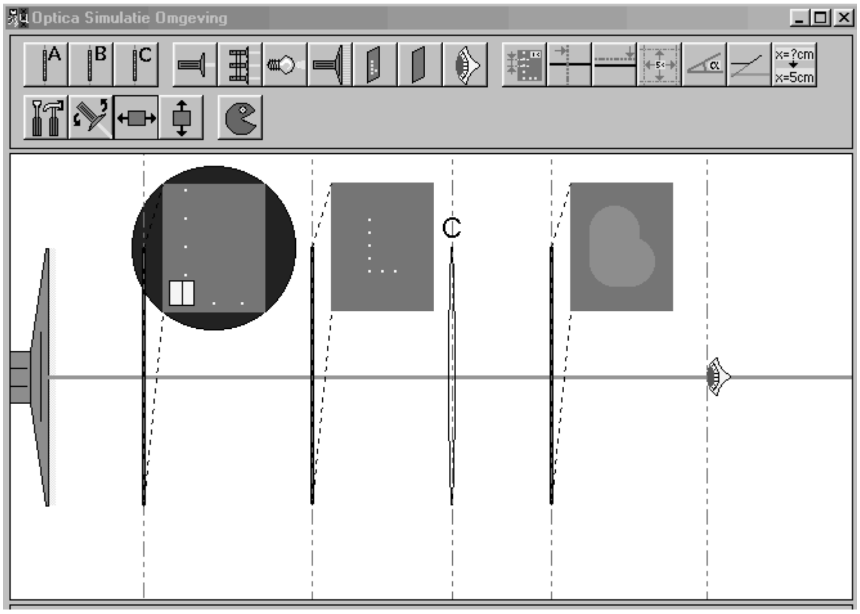

Figure 1. Example interface of the Optics computer simulation as used in the current experiment.

Two conditions were used in the study: a 'help'-condition, in which domain-specific knowledge was available to students during learning, and a 'no-help'-condition, in which students worked with the simulation but had no help available. Students were randomly assigned to one of the two conditions. In the help condition, tips were used to make domain-specific and generic knowledge available to subjects. Students were free to access the tips, they were not obliged to do so. In total, nine tips were available during learning. The assignment that was given to students was the same in both conditions. Students were encouraged to experiment with the simulation, and to find out the underlying rules.

To measure interaction behavior with the Optics simulation, all operations that students performed were registered by the computer. The resulting 'log files' could be analyzed afterwards. Before they worked with the simulation, paper-and-pencil tests for domain-specific and generic knowledge were administered to students. After working with the simulation, a domain-specific post-test was administered.

The experiment was split over two sessions: in the first session the prior knowledge tests were administered, in the second session students worked with the Optics simulation. Both sessions lasted about 80 minutes.

Results

The results showed that when students had access to information about geometrical optics, they did make use of it. Also, the information that was provided by the 'knowledge tips' helped in manipulating domain-specific knowledge, which in turn led to a statistically significant improvement on domain-specific knowledge from pretest to posttest (see Figure 2).

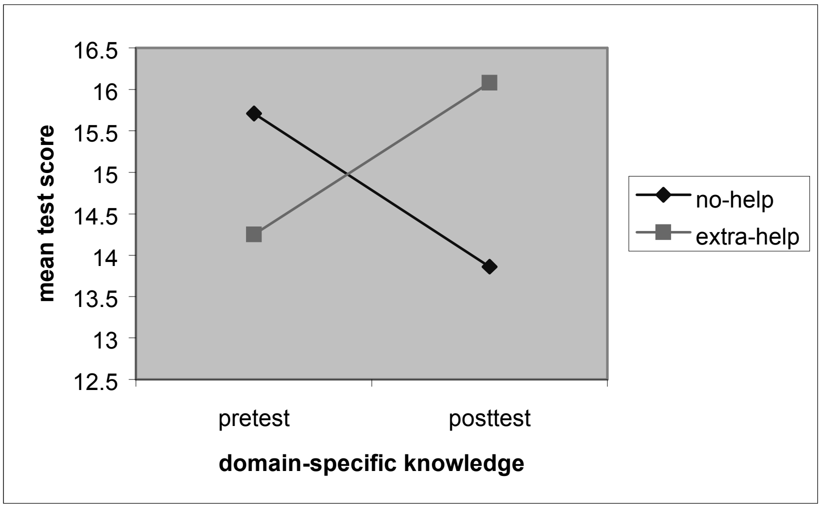

Figure 2. Pretest-posttest differences for no-help and help conditions.

The improvement from pretest to posttest in the help condition is in contrast to the result for the no-help condition. For the latter group, scores from pretest to posttest showed a statistically significant decrease. In the no-help condition a positive correlation between the domain-specific pretest and posttest was found (a replication of results from earlier experiments in which no support was used). This correlation was zero in the help condition. Also, no correlation was found between the number of tips that were accessed by subjects in the help condition, and their performance on the domain-specific posttest.

Results from the analysis of the interaction with the Optics simulation revealed that students in the help condition were less active than students in the no-help condition. When a division was made between students with poor and high generic prior knowledge, an opposite effect was found: students with high generic knowledge were more active than students with poor generic knowledge.

The results lead to the conclusion that discovery learning about geometrical optics can be rendered effective when a relatively minor support measure of knowledge support is used. When knowledge is offered during discovery learning, students are able to make use of it and will access it when they deem it necessary. The findings for the interaction behavior in the computer simulation replicate earlier findings: access to domain-specific knowledge leas students to be less active in their discovery learning behavior. Having generic knowledge of mathematical relations helps students in experimenting with a simulation, causing them to be more active. In terms of the SDDS model, it can be said that more generic knowledge gives students a larger hypothesis space to search, because they know of more types of possible relations between variables (in Van Joolingen and De Jong's extended SDDS model, this is called the 'effective learner space'). Having domain-specific knowledge available during discovery learning partly 'fills in' students' hypothesis space (or 'learner hypothesis space'), which reduces their need to search for further exploration.

Conclusions

The results of this study have both practical and theoretical implications. The practical implications center around the design of effective learning environments that elicit discovery learning. In earlier studies, we concluded that it is important to determine at what moment the availability of information can bring extra support to the discovery learning task and thereby improve performance in simulation-based learning environments (Hulshof, De Jong, & Van Joolingen, 1999). For these environments to be effective, it is important that students have access to (prior) knowledge during learning. Supporting students by giving them access to information during learning also has the potential benefit of motivating them to learn, because it will help them in linking the knowledge they receive with what they already knew about a subject.

On a more theoretical level, the study shows that the SDDS model, in which the search spaces are 'islands' of knowledge, is correct in adhering so much importance to the role of knowledge in discovery learning. Further research can shed more light on other determinants of successful discovery learning, and on the role of prior knowledge in collaborative discovery learning.

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