CONFRONTATION AND CO-CONSTRUCTION

EXPLORING AND SUPPORTING COLLABORATIVE SCIENTIFIC DISCOVERY LEARNING WITH COMPUTER SIMULATIONS

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EXPLORING AND SUPPORTING COLLABORATIVE SCIENTIFIC DISCOVERY LEARNING WITH COMPUTER SIMULATIONS

PROEFSCHRIFT

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de graad van doctor aan de Universiteit Twente,
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Voor Tante Hennie

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Hannie Gijlers
Hengelo, July 2005

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1. Collaborative scientific discovery learning

Abstract

In this first chapter, scientific discovery learning and collaborative scientific discovery learning are characterized. First, a general description of discovery learning is given in terms of 1) discovery learning processes and, 2) evolving knowledge. Subsequently, we introduce collaboration and explore the combination of discovery learning and collaborative learning in collaborative scientific discovery learning. We introduce a model to describe the evolving knowledge of two collaborating students. This model reveals that not only the prior knowledge of the individual student, but also the prior knowledge of the partner influences the knowledge acquisition process.

Discovering something by yourself can be a productive way of learning. The general idea is that students are more likely to recall concepts they discover on their own. Finding their own solution for a problem means that students have to engage in a search for information. However, not all discovery learning processes result in a successful learning outcome, and sometimes discovery learning can be a frustrating, instead of an exciting and stimulating task. Discovery learning is a complex undertaking for the majority of students and it may take a lot of struggling before students reach the point where they can call out “Eureka!” (Mayer, 2004). In computer supported scientific discovery learning environments a number of these problems can be overcome by integrating supportive tools into the environment (de Jong & van Joolingen, 1998) resulting in learning environments for inquiry or scientific discovery learning.

In this thesis we view scientific discovery learning as a collaborative endeavor in which guidance is not only provided by tools in the environment, but also by fellow students. The combination of scientific discovery learning and collaborative learning is promising because collaboration stimulates student to verbalize their ideas about the domain, elaborate on and discuss the idea of peer students, and assist each other when performing difficult aspect of the learning task. Collaboration encourages students to make their plans and ideas explicit and discuss them with their peers. It is expected that the verbalization and justification of plans and ideas will positively affect students’ learning process, both for the students who express themselves and for the students who receive this information. However, it is not likely that collaboration will solve all problems students experience with discovery learning. It is even possible that by combining discovery learning and collaborative learning new difficulties arise, that are for example, related to the communication between students (Kanselaar & Erkens, 1996).

In a collaborative learning setting students are confronted with the prior knowledge and actions of their partner. This implies that the scientific discovery learning process is not only influenced by the prior knowledge and actions of the individual students and their interaction with the discovery learning environment, but also by the prior knowledge and actions of their partner(s).

The central question of this thesis is to gain understanding of collaborative scientific discovery learning, and to investigate how the processes that comprise collaborative scientific discovery learning can be supported. The first part of this question focuses on the collaborative scientific discovery learning process. The majority of studies on scientific discovery learning focus on the scientific discovery learning of individuals and as yet little is known about the processes that occur when students work together on a scientific discovery learning task. In order to design effective support tools for collaborative scientific discovery learning it is important to gain insight in the learning processes that occur during collaborative scientific discovery learning. The second part focuses on the design and evaluation of tools to support students in a collaborative scientific discovery learning setting.

The central research question is investigated over the course of three studies, presented in Chapters 2, 3, and 4. The first study in this thesis focuses on scientific discovery learning processes and more specifically on the role of students' prior knowledge in a scientific discovery learning setting. Furthermore, the first study attempts to identify the possibilities and difficulties that occur during the collaborative scientific discovery learning process. The second study builds on the results of the first study and describes two tools designed to support students' collaborative scientific discovery learning process by offering them means to confront individual propositions of the domain. Finally, in the third study we describe and evaluate an extension of the collaborative scientific discovery learning environment used in the second study that offered students the possibility to collaboratively create an overall overview of the domain.

In the present chapter we present the theoretical framework of this thesis. First, we provide a description of scientific discovery learning and identify a classification scheme that can be used to describe the scientific discovery learning process. Subsequently, we introduce collaborative learning and then explore the possibilities and difficulties that might arise when scientific discovery learning and collaborative learning are combined into collaborative scientific discovery learning. Next, we introduce a model to describe the evolving knowledge of individual students engaged in a scientific discovery learning task, and, then adjust this model to describe collaborative scientific discovery learning processes.

1.1 Knowledge construction and scientific discovery learning

According the constructivist view on learning we construct our own understanding through reflection on our experiences. We relate new information and experiences to past knowledge. Often, this leads to a successful extension of our initial knowledge base but on other occasions we fail to make sense of a new experience (Hammer, 1996).

Constructivist instruction builds on this idea that students learn from experience. Modern technology can provide virtual environments for students to interact with and construct their own knowledge. For example, students can construct their own representation of a domain through *knowledge mapping* environments like Belvedere (Suthers, Weiner, Connelly, & Paolucci, 1995). The Belvedere system allows students to collaboratively construct knowledge representations in the form of concept maps and evidence maps. Students can view their maps in different formats like graphs or matrices. *Modelling environments* like ModellingSpace (Komis, Avouris, & Fidas, 2002) and CoLab (van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005) allow students to build qualitative- as well as quantitative- and runnable model of a domain. In the computer supported learning environment WISE different tools such as modeling tools, notes and hints, background information (evidence), and tools for data visualization can be combined to support students' knowledge inquiry learning process (Linn, Davis, & Bell, 2004).

In this thesis we focus on scientific discovery learning in simulation environments. *Computer simulations* are programs that contain a model of a real system or phenomenon. In this model relationships between different variables are described. Computer supported simulation environments are especially suited for scientific discovery learning. Discovery learning refers to the idea that students actively explore situations and instructional materials in order to ascertain domain concepts and underlying models. In a simulation environment students are invited to discover the relations between the variables. The model underlying the simulation is not disclosed to the students. Students infer knowledge about the simulated domain by exploring the simulation environment. In order to acquire knowledge from the learning environment students engage in a number of different processes, like stating hypotheses or rules, designing and performing experiments, and interpretation of experimental outcomes. Research indicates that the processes that comprise discovery learning appear to be difficult for the majority of students (de Jong & van Joolingen, 1998).

1.1.1 Discovery learning processes

In Section 1.1 we explained that discovery learning requires students to perform a number of complex and possibly unfamiliar processes. De Jong (in press) asserts that students act like real scientist and perform a number of processes that are quite similar to the ones in the empirical cycle (de Groot, 1969)

In literature many classification schemes for discovery learning can be found (Friedler, Nachmias, & Linn, 1990; Kuhn, Black, Keselman, & Kaplan, 2000). Most classification schemes distinguish similar processes. The four major categories are orientation, hypotheses generation, testing, and conclusion. De Jong and Njoo (1992) developed a classification scheme of the processes that basically comprise discovery learning. They distinguish between transformative processes (processes that directly yield knowledge) and regulative processes (processes that are necessary to control the discovery learning process). The transformative processes include orientation, hypothesis generation, experimentation, and data interpretation. The regulative processes include planning, verifying, and monitoring. The classification scheme used in this thesis is based on the work of de Jong and Njoo (1992) and, as they do, distinguishes orientation, hypothesis generation, experimentation, and interpretation. Below we will discuss these processes in more detail.

Orientation

During the orientation process, students search for information about the domain and task at hand. They identify the variables and parameters in the model and indicate the general properties of the model. Orientation can be done on the basis of the students' own prior knowledge, information available in the simulation environment, and additional information (for example provided by the teacher).

Proposition generation

The generation of hypotheses is regarded as one of the central processes in discovery learning. In a hypothesis students specify the relation between input and output variables. By stating, accepting, rejecting and/or refining hypotheses students build a mental model of the domain.

From a scientific viewpoint it is incorrect to refer to a hypothesis as true. A hypothesis that is confirmed, is not necessarily proven, but remains provisional. During the studies in this thesis students are asked to discuss and investigate the truth value of statements about relations. For this reason we chose to use the term proposition generation instead of hypothesis generation in this thesis.

Experimentation

During the experimentation process students decide upon the variables they want to manipulate and observe. They specify the value of the input variables and predict a possible outcome of the experiment. In order to gain information about propositions students must design and execute an experiment that is suited to put that specific proposition to the test.

Interpretation

Once students have conducted an experiment, they have to decide whether the experimental outcomes are inline with their predictions. Students have to interpret the experimental data in order to make a decision concerning the truth-value of propositions. Making sense of experimental outcomes can include a number of sub processes like extracting information from graphs and tables. Based on the interpretation of the data students can go back to their original proposition and draw a conclusion (see the processes of hypothesis generation).

Central in the discovery learning process is a students' understanding of the domain. During the *orientation*, the students' understanding of the domain is not yet complete. Students are not familiar with all the variables and relations that represent the domain knowledge. While orienting themselves on the domain students may specify their ideas about the relation between variables through a *proposition*. The truth-value of the specified proposition is still uncertain. In the process of experimentation students put their domain related ideas (as expressed in their proposition) through the test. The outcomes of the experiment need to be *interpreted* in order to reach full understanding of the data. Based on the interpretation of the data students revisit their proposition and decide whether the proposition needs to be accepted, rejected, or refined.

1.1.2 Problems experienced in a discovery learning setting.

Discovery learning has not always yielded better results than expository forms of instruction (de Jong & van Joolingen, 1998). Below we discuss a number of characteristic problems that learners encounter in a discovery learning setting. We will discuss the problems related to regulation and the main transformative discovery learning processes: orientation, proposition generation, experimentation, and the interpretation of data.

Regulative processes

Planning and monitoring of the discovery learning process is rather problematic for the majority of students. Students often plan only locally and do not keep track of the experiments they have conducted over the course of the learning session (de Jong & van Joolingen, 1998). This makes it difficult for students to take previous experimental outcomes into account.

Orientation

The orientation process can be problematic when students have only a limited amount of prior knowledge about the domain. Due to their limited prior knowledge students might fail to see important variables and potentially interesting relations.

Proposition generation

Students often find it difficult to construct an alternative proposition. Students tend to stick to their current proposition because they can not think of an alternative or because they find it difficult to change their initial ideas about the relations in the domain. Chinn and Brewer (1993) report that confrontation with anomalous does not necessarily, lead to the discounting of initial ideas. But sometimes leads to an alternative explanation in the direction of students' initial ideas. A study by Njoo and de Jong (1993) illustrates that students often fail to construct a syntactically correct and testable hypothesis.

Experimentation

Experiments can provide important information concerning the truth-value of a proposition. Unfortunately, students often design experiments that are not suited to test a specific proposition. A study by Dunbar (1993) indicates that students continue to search evidence for their current proposition even after they have observed contradicting evidence. Another problem is that student often design inconclusive experiments and vary too many variables at one time (Klahr, Fay, & Dunbar, 1993).

Interpretation

Once students have performed an experiment, the experimental outcomes need to be interpreted. Students often lack skills needed to interpret the data like reading graphs and extracting information from tables (Beichner, 1994).

1.1.3 Cognitive scaffolds

In order to address the problems students experience in a discovery learning setting various forms of guidance have been designed. Model progression, can be introduced to help students manage the complexity of the model. In model progression the model underlying the simulation is not offered in its full complexity from the start, but is gradually introduced. Another way to support students is to provide access to domain knowledge. This might be done by including a library or glossary with important definitions in the learning environment or by providing students Internet access. In order to overcome the problems students experience with the construction of propositions one can help them with expression builders that assist the students in building a syntactically correct proposition (van Joolingen & de Jong, 1991), prompt them to state relations (Quinn & Alessi, 1994) or, providing them with a list of predefined propositions (Njoo & de Jong, 1993).

To help student manage the different processes, structuring tools can be implemented in the learning environment. The WISE environment (http://wise.berkeley.edu/) combines a number of the aforementioned tools and contains a structuring tool that carefully scaffolds students in the process of collecting and comparing data and graphing their results. Internet sources can be added to the environment to provide students with extra information about the domain they are studying. The WISE environment also includes collaboration tools like a chat tool (Linn, Bell, & Davis, 2004). Students work in pairs on a WISE project. Working in pairs allows students to share ideas and guide and support each other.

1.2 Collaborative learning

There is a growing awareness that knowledge construction processes are often influenced by the social setting in which they take place (Scardamalia & Bereiter, 1993; van der Linden, Erkens, Schmidt, & Renshaw, 2000). In Section 1.1.1, we focused on the knowledge construction activities of individual students. Knowledge construction however, can also be described as a social cognitive process, were students co-construct knowledge. Collaboration, at this moment, is a widely used way to enhance the learning of students. Interaction between peers is believed to have a positive effect on the learning outcomes of students. In literature about peer learning the terms collaborative and cooperative learning occur frequently. In this thesis we focus on collaborative learning. In contrast to cooperative learning, collaborative learning focuses on a common goal that is shared by all students. The students share tools and activities in order to reach this goal (van Boxtel, van der Linden, & Kanselaar, 2000; Webb & Palincsar, 1996). When students are expected to share task, tools and activities, this will cause a natural need for interaction between the group members.

The positive effects of collaboration can be explained by the fact that engagement in a collaborative learning task provides students with the opportunity to talk about their own understandings and ideas. In a collaborative learning setting, students deal not only with their own prior knowledge and ideas about the domain at hand, but all partners contribute their knowledge to the learning process. When one of the partners has more knowledge, this partner might assist the less able partner by offering explanations (Teasley, 1995). Furthermore, students might experience that their own ideas and knowledge differ from the knowledge and ideas their partner holds, this can induce a so called socio-cognitive conflict. The term socio-cognitive conflict is based on the Neo-Piagetian perspective on collaborative learning. According to this theory controversy can enhance learning because it stimulates the deliberation of alternative propositions and explanations. A socio-cognitive conflict appears when a controversy between the viewpoints and ideas of collaborating students appears. The shock of the confrontation with other ideas might cause a state of disequilibrium that might result in construction of new knowledge in order to reach a state of equilibration again. The mere presences of contradicting ideas between partners, does not necessarily enhance learning (Damon, 1988). In order to benefit from socio-cognitive conflicts students have to detect these conflicts and be prepared to resolve the contradiction. Webb and Palincsar (1996), for example found that elaborated explanations and discussions are mediating learning, when students only provide short answers and explanations learning is not enhanced by collaboration. In order to resolve a conflict it is important that students have a knowledge base that allows them to construct new and more appropriate ideas.

1.3 Collaborative scientific discovery learning

Combining scientific discovery learning and collaborative learning is promising for various reasons. In Section 1.1.2, we discussed that scientific discovery learning can be a difficult process for students. A possible explanation for this is that the processes needed to construct knowledge from a discovery learning simulation are rather complex. In order to prevent these kinds of problems, several tools are designed to support, learners during their discovery learning process (see Section 1.1.3)

Not only tools, but also collaboration can support students during discovery learning. There is a number of reasons why collaboration can be very suited to take this role. First, real scientific discovery is often the result of joint effort of a number of researchers. Dunbar (2001) investigated the reasoning processes of scientist and concluded that the social interaction between scientists is conducive to scientific discovery. Dunbar (2001), therefore suggests that the social aspects that are important in scientific discovery should be introduced in science classrooms.

Second, in a collaborative learning setting students receive the opportunity to discuss their ideas about a scientific phenomenon with others. The activities and observations in a discovery learning setting provide shared experiences for collaborative knowledge construction. Students can discuss the experiments and various observations and speculate about their meanings. During this process they are likely to receive feedback or questions from their peers which might enhance reflection and elaboration. Elaboration seems to be positively related to learning outcomes (Webb, Nemer, & Zuniga, 2002).

Third, collaboration might address some of the problems students experience with the discovery learning processes. We addressed the issue that students frequently fail to identify relevant variables and the relation between those variables. Identification of relevant variables is difficult when students have relatively little prior knowledge about the domain. When students work with a more knowledgeable peer, this peer can provide extra information about the domain and even direct other students to relevant parts of the domain. Another problem is that students often not succeed at stating a syntactically correct proposition or generating an alternative proposition. In a collaborative learning setting, students have to discuss their ideas with a partner who might not share their ideas and might even suggest other ideas. Okada and Simon (1997) compared the discovery learning behavior of pairs and singles on a computer supported learning task in the field of genetics. Their results indicated that pairs were more successful than singles. Pairs engaged in more explanatory activities like generating hypothesis and considering alternative ideas. Okada and Simon (1997) argue that the generation of alternative ideas is often enhanced by a partners' request for information. With respect to the problems students experience with the interpretation of data collaboration can stimulate students to rethink their interpretation based on explanations or observations made by a fellow student. Miyake (1986) found that in a collaborative learning setting group members often serve as a sort of supervisor for each other. They observe what another member is doing and check their actions and might prompt them to rethink their interpretations.

It is known that planning and monitoring of the discovery learning process can become rather problematic (de Jong & van Joolingen, 1998). De Jong and Van Joolingen (1998) state that many students tend to plan only locally. For example, they do not take in account the experiments they have already have performed. Various studies have shown that successful students plan their experiments and pay significantly more attention to data-management (Schauble, Glaser, Raghavan, & Reiner, 1991; Shute & Glaser, 1990). In a collaborative learning setting there is a natural need for communication of plans and ideas. The fact that students in a collaborative scientific discovery setting are stimulated to verbalize their initial plans might help students become more aware of the planning and monitoring processes involved in scientific discovery learning.

1.4 Discovery learning as evolving knowledge

In Section 1.1.1 discovery learning was described in terms of a number of different learning processes. Engaging in different discovery learning processes might lead to changes in the knowledge base of students. Discovery learning can also be described in terms of evolving knowledge, by describing discovery learning in terms of search spaces (Shunn & Klahr, 1995; Simon & Lea, 1974). Klahr and Dunbar (1988) described discovery learning as a search process in two search spaces: the hypothesis space and the experiment space. In the model of Klahr and Dunbar the hypothesis space contains all rules and variables describing the domain. The experiment space consists of all possible experiments that can be performed within the domain. The so-called SDDS model (Scientific Discovery as Dual-space Search) can be seen as a general model of scientific reasoning that can be applied to any context (Klahr & Dunbar, 1988)

To make the SDDS model suited for describing discovery learning processes in complex domains, Van Joolingen and De Jong (1997) extended the SDDS model. They introduced different regions in hypothesis space and designed a taxonomy to describe relevant search operations in the distinguished search spaces. In Figure 1-1, a graphical overview of the different regions in hypothesis space (adapted from van Joolingen & de Jong, 1997) is provided. The configuration presented in Figure 1-1, is an example configuration; other configurations of the presented search spaces are possible.

The universal hypothesis space contains all possible hypotheses that can be stated about the domain, irrespective of their truth-value. The learner hypothesis space is a subspace of the universal hypothesis space and contains the students' knowledge about the variables and relations in the domain, irrespective of their truth-value. The learner hypothesis space defines the part of the universal hypothesis space that the learner can directly search (without additional information from, for example a teacher, textbook or learning environment). A variable or relation in the learner hypothesis space is not automatically considered relevant or worthwhile testing by the student. The learner domain space represents the learners' beliefs and ideas about the domain, and represents a students' current knowledge state. The target conceptual model consists of propositions that are valid in the domain and covers the knowledge to be discovered. During the discovery learning process the learner's knowledge base changes, and therefore the configuration of the extended SDDS model will also change during the learning process. The decomposition of the hypothesis space in regions provides opportunities for a detailed description of how students' knowledge evolves in a scientific discovery learning setting.

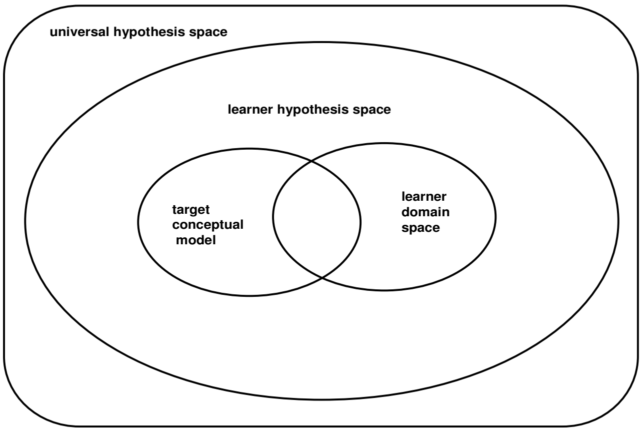

Figure 1-1. The extended SDDS model

The configuration as sketched in Figure 1-1, is one example of a knowledge configuration. Knowledge configurations are based on a students' individual knowledge base. This knowledge base varies across students and results in a wide variety of individual knowledge configurations. In Figure 1-2 several other examples, labelled A, B, and C, are presented. We will discuss the possibilities and difficulties that might occur in the presented examples.

In configuration A there is no overlap between the student's actual knowledge (the learner domain space) and the target conceptual model. This implies that, at this moment, the student does not posses relevant domain knowledge. Since the target conceptual model falls completely in the learner hypothesis space, this student is able to state relevant propositions and infer information about the target conceptual model.

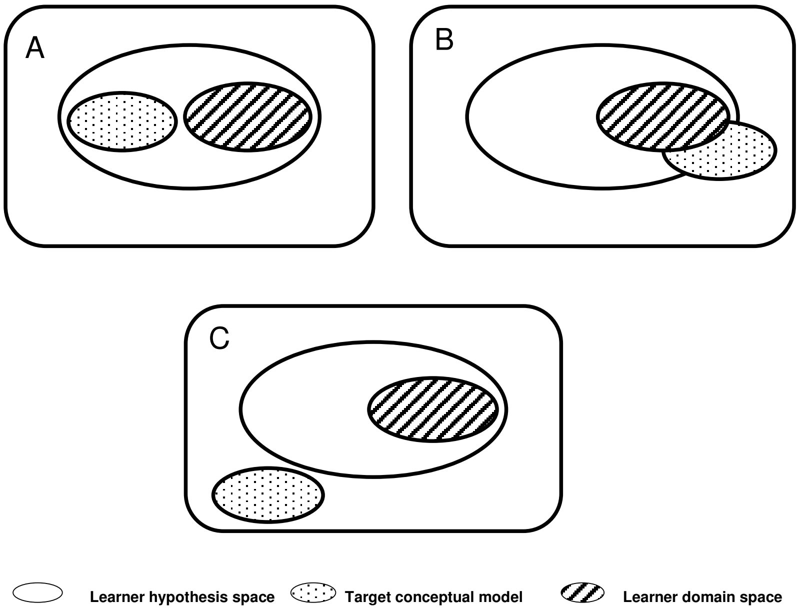

Figure 1-2. Some examples of knowledge configurations

In configuration B, there is some overlap between the target conceptual model and the learner domain space which means that the learner has some knowledge of the domain and/or holds some relevant proposition in consideration. Part of the target conceptual model, however, lies outside the learner hypothesis space, which implies that the student has to enlarge the learner hypothesis space, before all propositions concerning the target conceptual model can be stated. The student may enlarge the learner hypothesis space by bottom-up exploring a simulation, look for new information in a textbook, or consult teacher. Finally, in configuration C, the target conceptual model is completely outside the learner hypothesis space which means that the learner needs to learn all relevant variables and relations before being able to state relevant hypotheses.

Various states of knowledge can be represented with the extended SDDS model. In Figure 1-3, a number of propositions are placed at different locations in the model. We distinguish propositions of which the students have already decided whether they think the specific proposition is true (assessed the truth-value) and propositions of which the truth-value still is unknown by the student. The combination between a certain proposition and its location in the model offers the possibility to represent different kinds of knowledge. For example, when the truth-value of a specific proposition has not been established and this proposition is located in the overlap between the target conceptual model and the learner domain space this proposition is correctly considered as possibly true. In Figure 1-3 the different states of knowledge are labeled.

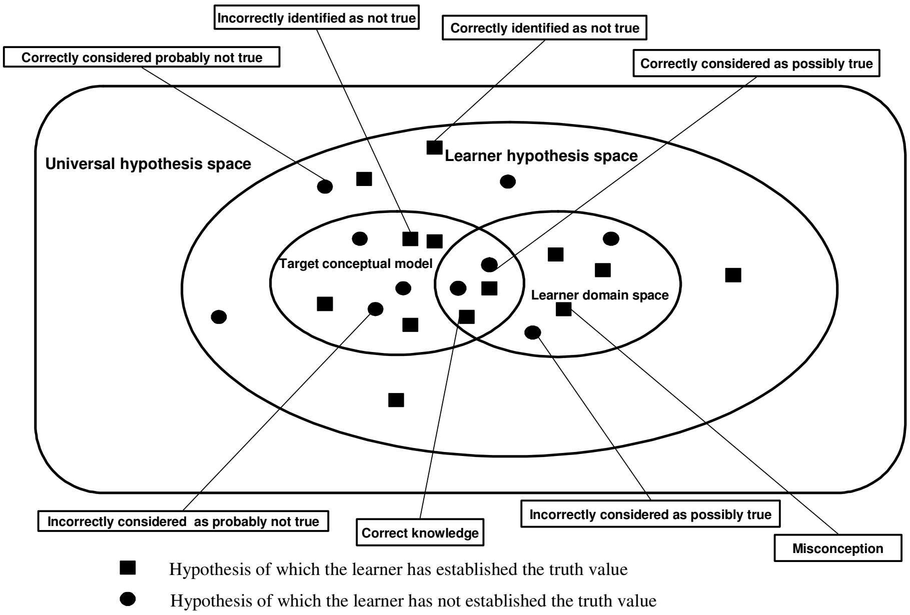

Figure 1-3. Overview of various states of knowledge that can be represented by the extended SDDS model

1.4.1 Evolving knowledge

A central issue to the model of Van Joolingen and De Jong (1997) is that knowledge configurations, as the ones in Figure 1-2, are *dynamic* ones. When students gain knowledge about the underlying model their learner domain space moves toward the target conceptual model. The two spaces that are fixed are the universal hypothesis space (the set of hypotheses that can be stated in principle) and the target conceptual model (the set of hypotheses that describes the domain to be discovered). What can change during the discovery learning process are the two learner spaces: the learner hypothesis space and the learner domain space. The learner hypothesis space changes when the learner is capable of stating hypotheses that he or she could not state before. This happens, for example, when the student learns new relations that can be used in creating hypotheses. The learner domain space may change during experimentation. Propositions that are not confirmed through experimentation might be excluded from the learner domain space. The learner domain space enlarges when students consider additional propositions as being correct. The ultimate goal is that there is a complete overlap of the learner domain space and the target conceptual model.

Figure 1-4 provides an example of a configuration of knowledge as it might develop in a learning process. In configuration A the target conceptual model is located partly outside the learner hypothesis space, and there is no overlap between the target conceptual model and the learner domain space. This implies, most probably, that the student does not consider testing the propositions located in the target conceptual model and does not possess all knowledge needed to create the propositions necessary to cover the target conceptual model. As a first step, for example, instruction may be given to ensure that the student could create all propositions covered by the target conceptual model. This might be done, for example by training the learner in the necessary mathematical relations. This results in a situation as the one given in configuration B (in Figure 1-4). In configuration B the learner hypothesis space has extended and now includes the target conceptual model. In a process of experimenting, finding evidence about propositions, considering new propositions to test, testing again, the learner domain space changes its shape and moves towards the target conceptual model (depicted in configuration C). Ideally, this process will lead to a situation as depicted in situation D, in which there is a complete overlap of learner domain space and target conceptual model. In practice, this overlap will hardly ever be complete, students seldom reach perfect knowledge.

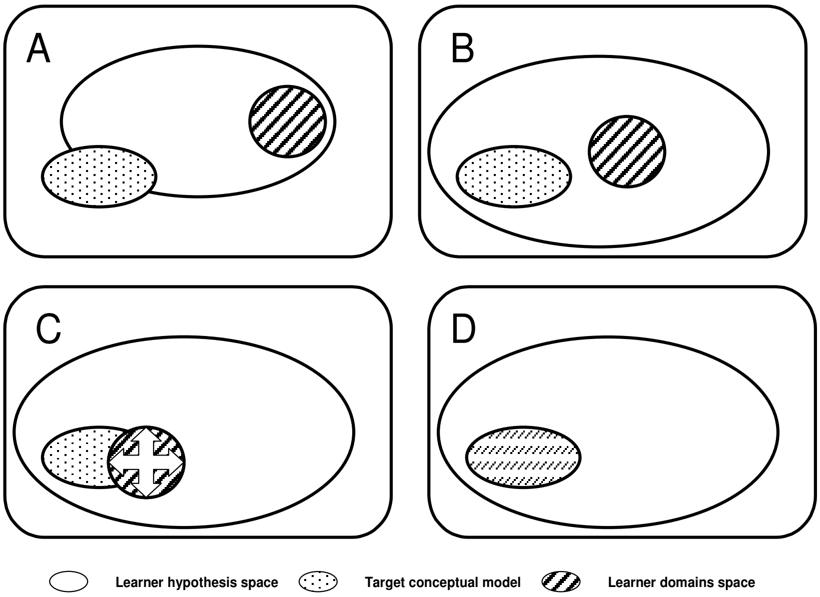

Figure 1-4. An example of a developing knowledge configuration

1.5 Towards a model of collaborative discovery learning

In Section 1.3 we discussed that collaborative scientific discovery learning can be interesting for a number of reasons. One of the identified reasons was that collaboration might help students overcome some of the difficulties that are associated with the discovery learning process. Within a collaborative learning environment two or more students interact. Students might comment on each other's ideas and provide support and explanations to one another. Hence students might be influenced by each other's knowledge base. Until now, most models describing discovery learning focus on the learning process of individual students. According to Okada and Simon (1997), however, a model of collaborative discovery learning should describe the evolving knowledge of all participants. Students do not only deal with their own prior knowledge and the information and data provided by the simulation environment, but also have to deal with their partners prior knowledge, requests, and critiques. A proposition stated by one student is likely to influence the search process of a peer student. In this way knowledge is co-constructed by the collaborating students.

In Section 1.4 Van Joolingen and De Jong's (1997) extended SDDS model was presented. This model makes it possible to represent the knowledge base of a student in a configuration. The extended SDDS model (van Joolingen & de Jong, 1997) can be adjusted to a model describing the learning process of two students working together on a scientific discovery learning task.

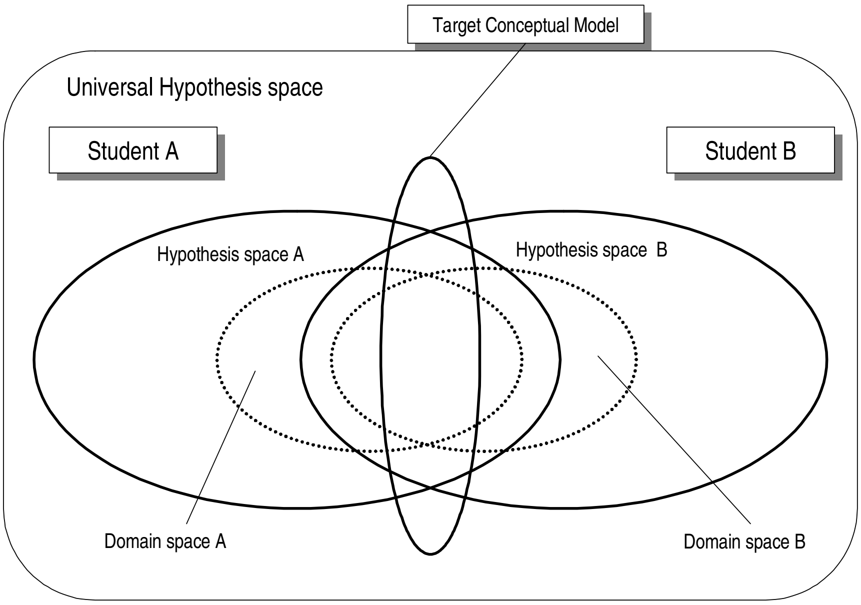

Figure 1-5. The extended SDDS model for two students

In the model presented in Figure 1-3, different states of knowledge were represented. Figure 1-5, presents the extended SDDS model for two students; this model offers the possibility to represent these states of knowledge for two collaborating students. Furthermore, the model allows us to distinguish individual and shared prior knowledge. This distinction is important because not all knowledge, assumptions, and ideas are shared. The overlap between the learner domain spaces of two students represents the propositions that both students consider being true. This overlap, between learner domain spaces of collaborating students can be seen as a common search space. It can be said that the overlap depicts common ground of mutual understanding, knowledge, beliefs and assumptions that has been claimed to be necessary for many aspects of communication (Baker, Hansen, Joiner, & Traum, 1999).

Different combinations of prior knowledge may lead to different learning processes and different kinds of interaction. When students share a lot of prior knowledge and there is a substantial overlap of the learner domain spaces with the target conceptual model there is no need for long discussions and explanations. However, when both students have the same knowledge gaps, pooled ignorance might occur (Xin, 2002). Figure 1-6 illustrates how differences in prior knowledge may lead to different learning processes. Configuration A, displays an example of a configuration, where the both students are familiar with the proposition. The square indicates that both students consider the proposition to be true. This assumption is right because the proposition is also located in the target conceptual model. The proposition in configuration A, is part of both students prior knowledge base. Students may build on this proposition by refining the proposition or investigating the effect of another variable on the relation stated in this particular proposition.

Like in configuration B, students enter the discovery learning setting with different beliefs and prior knowledge, concerning a specific proposition. Configuration B shows an example of a proposition of which the truth-value has not yet been established. In this case the "true" proposition is located within the learner domain space of student A, and in the hypothesis space of the student B. This implies that student B in contrast to student A does not label this specific proposition as true. Student A can explain why he or she considers this particular proposition to be true and learning might occur.

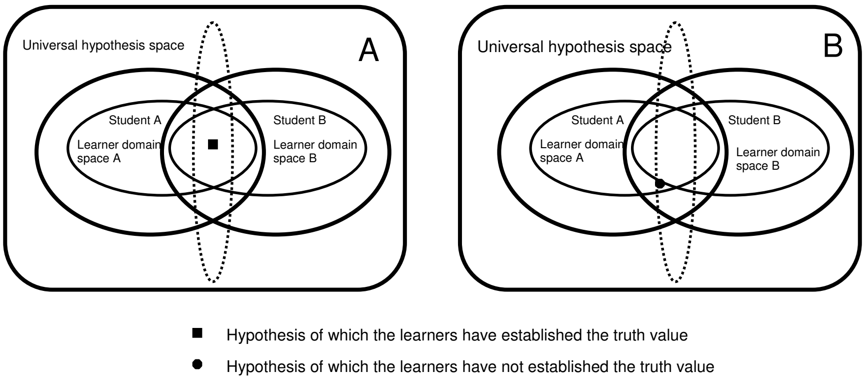

Figure 1-6. Some example configurations of the extended SDDS model for two students

The extended SDDS model for two students also illustrates that not only the level of prior knowledge is important for the collaborative discovery learning process, but also the state of prior knowledge (represented by its location in the extended SDDS model, and the assigned truth-value). The model illustrates that students with different prior knowledge bases can learn from each other, because students can explain ideas and theories to one another. In the present thesis the extended SDDS model is used to describe, the role of prior knowledge, and the development of students' knowledge configuration during the collaborative learning process (Chapter 2).

1.6 Summary and outlook

This thesis started with a description of discovery learning and collaborative learning. We discuss two approaches to describe the discovery learning process. The first approach focuses on a classification of the processes that basically comprise discovery learning. The second approach focuses on students' knowledge development. In the present chapter we discussed the extended SDDS model (van Joolingen & de Jong, 1997) to describe the knowledge development of an individual student. We introduced an adjusted version of the extended SDDS model suited for describing the evolving knowledge of two collaborating students. Based on the extended and adjusted SDDS model for two students we conclude that combining discovery learning and collaborative learning into collaborative scientific discovery learning is a promising endeavor. However, it is not to be expected that collaboration will solve all problems students experience during the discovery learning process. Problems identified in research on collaboration such as maintaining a common focus (Saab, Van Joolingen, & Van Hout-Wolters, 2005, Kanselaar & Erkens, 1996), and differences in prior domain knowledge, are likely to influence the collaborative discovery learning process. Support is needed to fully capitalize on the potential benefits of collaboration in the context of scientific discovery learning.

The main question guiding the research in this thesis is;

> *How can we create a computer supported learning environment that effectively supports collaborative scientific discovery learning?*

In order to design effective support it is important to understand the characteristics of the collaborative scientific discovery learning process and the evolving knowledge base. Therefore, the research reported in this thesis starts with an exploration of the collaborative scientific discovery learning process and the influence of the individuals' prior knowledge on the collaborative discovery learning process. The first study identifies a number of difficulties and possibilities for collaborative scientific discovery learning. The results of the first study will be discussed in Chapter 1. Based on the results of the first study, the second and third study, introduce and evaluate tools to support the collaborative scientific discovery learning process.

In Chapter 3, three different versions of a learning environment on one dimensional kinematics, were compared. Students in the first (control) group worked with a version of the learning environment without specific guidance, student in the second group were supported with a shared proposition scratchpad (expression builder). The proposition scratchpad provided students with lists of variables and relations that can be used to compose a proposition. The third group of students worked with a shared proposition table. The shared proposition table is based on students' individual judgments of the truth-value of a list of ready made propositions. Upon entering the learning environment student were coupled into dyads and their individual judgments were combined in one shared proposition table, displaying the opinion of both students. Students in all three conditions were provided with a chat tool to facilitate communication. Both tools are designed to trigger the communication about the generation, truth- value and testing of propositions.

In Chapter 4 we report on a study comparing two groups of students working with a simulation environment including the shared proposition table. The experimental group additionally created shared concept maps, to support them to get an overview of the domain.

In Chapter 5 we discuss the results of three studies in the light of the theory presented in the present chapter. The chapter concludes with offering suggestions for educational practice and future research.

2. The influence of prior knowledge on students’ dialogue during collaborative scientific discovery learning[1]

Abstract

This study investigates how prior knowledge influences knowledge development during collaborative scientific discovery learning. Fifteen dyads of students (pre-university education, 15-16 years old) worked on a scientific discovery learning task in the physics field of kinematics. The (face to face) communication between students was recorded and the interaction with the environment was logged. Based on students’ individual judgments of the truth-value and ‘testability’ of a series of domain specific propositions, a detailed description of the ‘knowledge configuration’ for each dyad before they entered the learning environment was created. Qualitative analyses of two dialogues illustrated that prior knowledge influences the discovery learning processes and knowledge development in a pair of students. Assessments of students’ and dyad’s definitional (domain specific) knowledge, generic (mathematical and graph) knowledge and generic (discovery) skills were related to the students’ dialogue in different discovery learning processes. Results show that a high level of definitional prior knowledge is positively related to the proportion of communication regarding the interpretation of results. Heterogeneity with respect to generic prior knowledge was positively related to the amount of utterances made in the discovery process categories ‘proposition generation’ and ‘experimentation’. The results of the qualitative analyses indicated that collaboration between extremely heterogeneous dyads is difficult when the high achiever is not willing to scaffold information and work in the low achiever’s zone of proximal development.

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[1] This chapter is an adapted version of Gijlers, H., & de Jong, T. (2005). The relation between prior knowledge and students’ collaborative discovery learning processes. *Journal of Research in Science Teaching, 42*, 264-282.

2.1 Introduction

There is a vast body of research on the effects of discovery learning (see e.g., de Jong & van Joolingen, 1998; Friedler, Nachmias, & Linn, 1990; Reiman, 1991) and also on the effects of collaborative learning (Rochelle, 1996; Webb, 1991) but less attention has been given to the combination of collaboration and discovery. The majority of studies on scientific discovery learning focus on discovery learning by individuals and as yet only a few studies (Roth & Roychoudhury, 1992; Teasley, 1995) have investigated the processes that occur when students work together on a discovery learning task. Okada and Simon (1997) stress that a model for collaborative discovery learning should take into consideration the prior knowledge and actions of all group members. In this study we introduce a model to describe the knowledge states of two collaborating students in a discovery learning setting. From this model we will discuss the influence of prior knowledge on collaborative discovery learning.

Discovery learning encourages students to be active agents in their own learning process. Within a discovery learning environment the students' main task is to find the properties of a domain. These properties are not presented to the students in a direct manner, but are to be discovered through experimentation and interpretation. Two approaches can be identified in previous research on discovery learning. The first approach puts an emphasis on the discovery learning processes, the second approach focuses on knowledge development.

Discovery learning processes have been classified following different classification schemes (see e.g., Friedler et al., 1990; Kuhn et al., 2000; Njoo & de Jong, 1993; Teasley, 1995; White, Shimoda, & Frederiksen, 1999). In this study we use the classification scheme of Njoo and de Jong (1993). Njoo and de Jong (1993) make a distinction between transformative processes and regulative processes. Regulative processes refer to the control over the learning process. Examples of regulative processes are planning and monitoring. Transformative processes are processes that more or less directly generate new knowledge and comprise processes such as analysis (orientation), proposition generation, experimentation, and interpretation. During orientation, students search for information about the domain and the task at hand. They identify the variables and parameters in the model and indicate its general properties. *Orientation* can be done on the basis of the students' own prior knowledge, the group's prior knowledge (in a collaborative setting), additional information, and information available in the learning environment. *Proposition generation* can be seen as one of the central processes in discovery learning. In a proposition, students specify the relation between input and output variables. Through the stating, accepting rejecting and/or refining propositions students build a mental model of the domain. *Experimentation* refers to all activities that deal with the design and execution of experiments. In an experiment students put the ideas (as expressed in a proposition) through the test. *Interpretation* concerns activities that deal with the interpretation of data and results. After the interpretation of the data students can revisit the proposition and draw a conclusion about the truth-value of the proposition. When necessary students can decide to refine the proposition or state an alternative proposition.

Another approach in research on discovery learning describes the discovery learning process in terms of evolving knowledge. Klahr and Dunbar's (1988) SDDS (Scientific Discovery as Dual Search) model is an example of this approach. The SDDS model describes discovery learning as a search process through two spaces: the hypothesis space and the experiment space. The hypothesis space is the search space that contains all rules describing the phenomena that can be observed within the domain. The experiment space consists of all experiments that can be performed within the domain. To portray discovery learning in complex domains van Joolingen and de Jong (1997) extended the SDDS model. They introduced different regions in hypothesis space and designed a taxonomy to describe different search operations (see also Chapter 1). Figure 1-3 provides a graphical overview of the different regions in the hypothesis space (based on van Joolingen & de Jong, 1997).

The universal hypothesis space contains all hypotheses that could possibly be stated. The learner hypothesis space is a subspace of the universal hypothesis space and contains all propositions, variables, and relations the learner knows of and that he or she could possibly use to describe the domain to be discovered. The learner domain space is a subset of the learner hypothesis space and represents the learner's knowledge concerning the domain and indicates the propositions the learner thinks are true or considers as possibly true in the domain. The target conceptual model describes the propositions that are valid in the domain and covers the knowledge to be discovered. During the discovery learning process the knowledge base of the learner changes. When students gain knowledge about the underlying model, their learner domain space moves toward the target conceptual model. This implies that the extended SDDS model is a dynamic model that changes during the process of discovery learning.

Within the extended SDDS model we distinguish propositions of which the student has already assessed the truth-value and propositions of which the truth-value is still unknown to the student. The propositions can be located in different regions of the extended SDDS model (see Chapter 1, Figure 1-3). The truth-value a students assigned to a certain proposition combined with it's location in the SDDS model creates the possibility to create a graphical representation of a students' knowledge configuration. For example, when the truth-value of a certain proposition has not been established and this proposition is located in the overlap between the target conceptual model and the learner domain space this proposition is correctly considered as possibly true (see also Chapter 1).

The extended SDDS model as presented in Figure 1-3 represents the knowledge configuration of a single student. Within a collaborative discovery learning setting two or more students interact with each other. This implies that there is feedback not only from the experimental outcomes, but also from a partner's prior knowledge. The alternative propositions stated by student A, are likely to influence the search of student B. A gap in the knowledge of student B might be filled in by knowledge from student A. In this way knowledge is co-constructed by the collaborating students. The extended SDDS model as presented in can be adjusted to a model representing the knowledge configuration of two students working together on a scientific discovery learning task.

In the model presented in Figure 2-1, individual and shared knowledge can be distinguished. This distinction is important because not all knowledge and assumptions are shared. Propositions, variables, and relations that a student considers are represented by the learner domain space. When two students work together they might agree on some ideas and disagree about others.

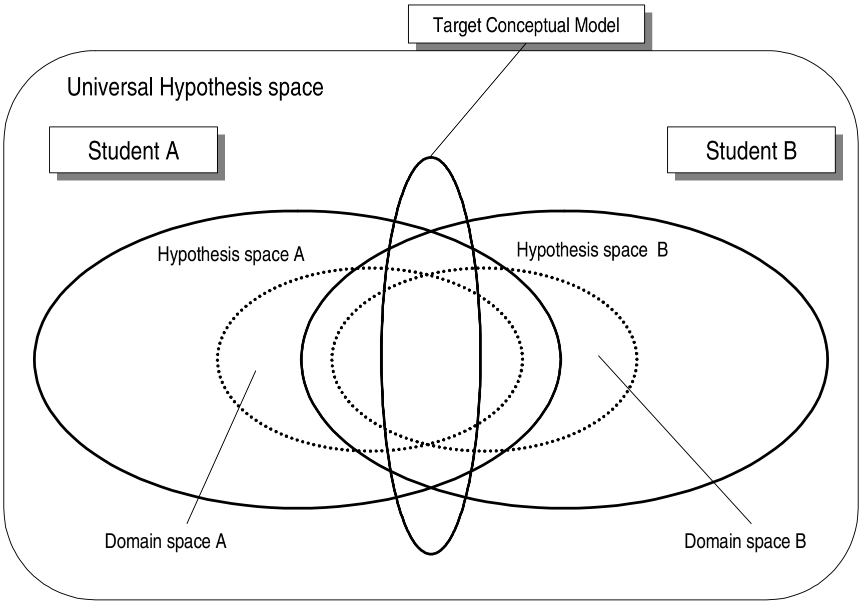

Figure 2-1. The extended SDDS model for two collaborating students

The overlap between the learner domain spaces of both students can be described as a common domain space. We can say that the overlap depicts the common ground of mutual understanding and shared assumptions that have been claimed to be necessary for many aspects of communication (Baker et al., 1999). The non-overlapping parts display students' individual knowledge.

Different combinations of prior knowledge within a dyad might lead to different communication and learning processes. Imagine a dyad of students working within the physics domain of kinematics, e.g., with a simulation of the braking distance of a scooter. They consider the following statement: "If the velocity of a scooter is enlarged by a factor of two the braking distance of the scooter is also enlarged by a factor of two". Student A knows that this statement is not true, whereas Student B thinks the statement is true. In Figure 2-1 this is represented by the fact that the proposition (a black square) is located within the hypothesis space of student A, but outside the learner domain space of student A and within the learner domain space of Student B. The proposition is not located within the target conceptual model, which indicates that the statement in this proposition is not true. In this case the first student might start explaining to student B that there is no direct positive linear relationship between scooter speed and braking distance. In this particular situation student B has the opportunity to learn something from student A. However, if both students had thought the proposition was true, it would become more difficult to resolve the misconception. If both students considered the hypothesis as possibly true but were not sure, this could encourage them to do an experiment. This example illustrates the potential influence of individual prior knowledge on discovery learning processes within a dyad. If the students have different opinions or prior knowledge this is of possible influence on their discovery learning process, i.e. in the above example student A could scaffold the knowledge for student B.

Differences in prior knowledge and their influences on the learning process have been studied extensively in the literature (Vygotsky (Vygotsky, 1962, 1978; Webb, 1991). Vygotsky (1978) discusses collaboration within the zone of proximal development. The zone of proximal development is described by Vygotsky as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p.86). This indicates that students can perform certain tasks under the supervision of a more capable person (for example an adult) that they cannot perform on their own. From Vygotsky’s perspective, students have different roles during the learning process. The more capable peer guides the less capable peer during the learning process. A similar approach is advocated in the work by Newman, Griffin, and Cole (1989) who describe collaboration as knowledge scaffolding by an expert and knowledge appropriation by the novice. Newman, et al., (1989) further expound on these concepts in their discussion of the construction zone. The construction zone is an interactive zone were students work together on problems that one of them could not solve individually. Cognitive change takes place within the construction zone. The supportive structure is not only determined by the support students receive from each other but also by the environment and the task structure.

Furthermore, a collaborative learning setting provides the students with the opportunity to discuss alternative hypothesis. According to Kneser and Ploetzner (2001), and Okada and Simon (1997) the discussion of alternative hypotheses is an important aspect of collaborative discovery. Okada and Simon (1997) for example, compared dyads and individuals working on a discovery learning task. They found that pairs were more successful. Additionally, pairs discussed and constructed more alternative hypotheses.

These alternatives may reveal individual misconceptions that become apparent through verbalization (Vahey, Enyedy, & Gifford, 2000). In the present study we explore collaborative discovery learning. To be more precise we focused on the influence of prior knowledge on the development of knowledge and the associated learning processes within a collaborative discovery learning context. In a discovery learning environment built around a simulation in the domain of kinematics, we investigated the knowledge development of dyads of students. We assessed prior knowledge by a number of assessment methods. A hypothesis test was developed to assess students' prior knowledge and beliefs about the hypothesis within the domain. More traditional tests were used to assess generic knowledge and definitional domain knowledge. Dyads of students worked together on a collaborative discovery learning task. Based on the test results and transcribed protocols, developing knowledge configurations were assessed.

2.2 Method

2.2.1 The domain

The learning environment in this study concerned the physics domain of kinematics. The domain of kinematics is prone to misconceptions. The misconceptions of students are grounded in extensive personal experiences and instruction (Halloun & Hestenes, 1985b). Research has shown that students taking an introductory physics course, on a university level, still experience serious trouble with kinematics. Trowbridge and McDermott (1980) studied university students' reasoning about position, velocity and acceleration. They found that even after instruction, about 20 percent of the students still confused the concepts of speed and acceleration. Computer simulations can address some of the problems students' experience in the domain of kinematics. The animation of motion combined with a graph can help students understand kinematical graphs.

2.2.2 The learning environment

In the present study, students worked with a computer-based simulation environment in which the central part was a simulation on kinematics. The learning environment was developed with the SimQuest authoring environment (van Joolingen & de Jong, 2003). More information on SimQuest and examples of applications developed with SimQuest can be found on www.SimQuest.nl[2].

Students worked together in a face to face setting. Sharing a tool and a task created a natural need to communicate and share ideas. In the learning environment students manipulated values of input variables, and observed the behavior of output variables. Output was presented to the students in the form of animations, graphs and numbers.

In order to guide the student during the learning process the learning environment contained instructional support. The full model of a simulation is often very complex. We used model progression (White & Frederiksen, 1990) and divided the domain into four levels: an introductory level and three progression levels. The introductory level was developed to introduce learners to the learning environment. The model in the, first, level focused on initial velocity, acceleration, time and final velocity $v(t) = v(0) + a \cdot t$). The relevant variables were presented to the student one at a time. In the first progression level students could test propositions such as: "if the acceleration of a car equals zero than the final velocity of this car will equal the initial velocity". Within the second progression level the students worked with simulations on distance covered. In the third, and final, progression level the concepts mass and friction were introduced to the students. After the introductory level learners were free to start at any level and move back and forth between them.

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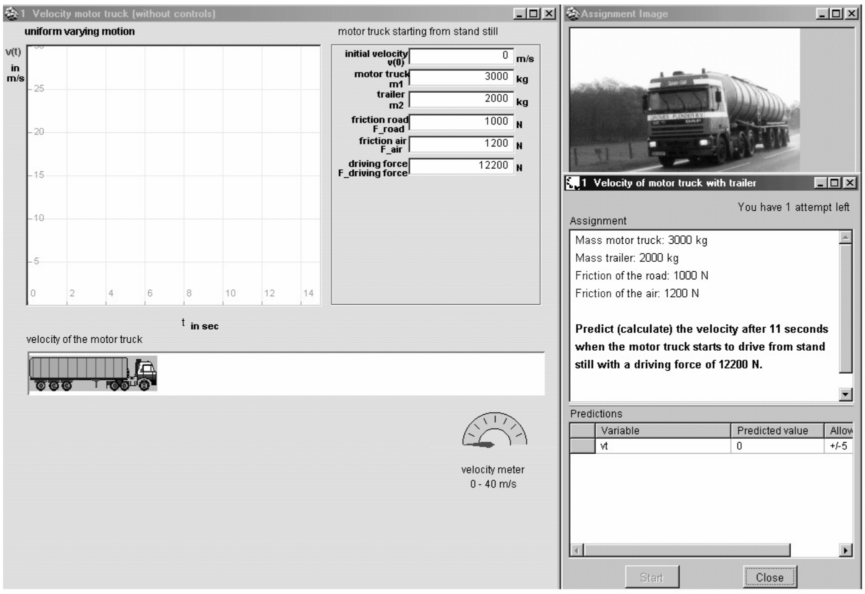
[2] The SimQuest application MOTION, used in all studies reported on in this thesis was developed by Jan van der Meij.

Assignments were used to guide students through the key elements of the simulation and provide them with short-term goals. Together with model progression, assignments disaggregated the complex model into smaller portions. In this learning environment we used different types of assignments. Some assignments asked students to find the relation between two or more variables (investigation assignments), other assignments asked the learners to explain a specified relation (explication assignments), and still other assignments asked students to predict the value of a variable under specified conditions (specification assignments). Figure 2-2 displays a simulation of a truck and an assignment. The (specification) assignment in Figure 2-2 is taken from the third progression level. The truck in the simulation starts from stand still. Students are asked to predict the velocity of the truck after 11 seconds. They are provided with information about the mass of the motor truck and the trailer, friction from the road, friction from the air, and the driving force.



motor truck starting from stand still

initial velocity v(0): 0 m/s
motor truck m1: 3000 kg
trailer m2: 2000 kg
friction road F_road: 1000 N
friction air F_air: 1200 N
driving force F_driving force: 12200 N

You have 1 attempt left

Assignment

Mass motor truck: 3000 kg
Mass trailer: 2000 kg
Friction of the road: 1000 N
Friction of the air: 1200 N

Predict (calculate) the velocity after 11 seconds when the motor truck starts to drive from stand still with a driving force of 12200 N.

Predictions

Variable	Predicted value	Allow
vt	0	+/-5

Figure 2-2. Screendump of the SimQuest learning environment

2.2.3 Sample

The sample consisted of thirty fourth year (15-16 years old) high school students (15 male and 15 female) in the Netherlands. All students were from the same school and followed a university preparation track. Prior to this study, students completed an introduction to kinematics in their regular physics classess. This introduction covered the definitional knowledge needed for working in the simulation environment. Subjects participated in the study on a voluntary basis and received a small reward for their participation. Subjects were randomly paired with another student. All subjects had sufficient computer experience.

2.2.4 Knowledge tests

Different tests were used to assess the different kinds of prior knowledge and students' knowledge configurations. A definitional knowledge test was used to assess students' knowledge of concepts and variables in the domain. A generic knowledge test focused more on students' ability to work with mathematical relations, such as their ability to interpret graphs and experimental outcomes and their discovery skills. The TIPS II (Test of Integrated Process Skills II;, Burns, Okey & Wise, 1985), TOGS (Test Of Graphing in Science; McKenzie & Padilla, 1986) and the TUGK (Test of Understanding Graphs in Kinematics, Beichner, 1994) inspired our generic knowledge test. The propositions test focused on students' judgment of the truth-value of a set of domain specific propositions.

Definitional knowledge test

Swaak and de Jong (1996) defined definitional knowledge as declarative conceptual knowledge. The objective of the definitional knowledge test is to assess if students know the concepts and variables that were relevant in the learning environment. In this study we tried to determine if students knew the concepts that are important in the domain of kinematics, like acceleration, air friction and velocity. The definitional knowledge test consisted of 22 multiple-choice items (with four answer alternatives). Of the 28 students from whom the data were analyzed there was an average score of 12.67 (SD = 4.59). Cronbach's Alpha for the test was .83, which indicates high internal consistency.

Generic knowledge test

Generic knowledge can be defined as the knowledge that is needed to recognize and work with numerical and graphically depicted relations between two or more variables (Ploetzner & Spada, 1992). Knowledge about relations is needed to state hypotheses about relations between variables and to interpret the results of experiments. In our study this implies that we have to assess whether or not a student possesses the knowledge and skills that are needed to understand qualitative and quantitative relations in a general way. The generic knowledge test consisted of 36 items. The average score of the 28 students from whom data were analyzed, was 26.65 (SD = 5.61). All items were multiple-choice questions with four answer alternatives. The test was divided into three sections. The first section consisted of 13 items and was designed to assess the students' knowledge about mathematical relations (Cronbach Alpha .74). The second section also consisted of 13 items and measured the ability to work with graphs (Cronbach Alpha .61.) The third section consisted of 10 items and examined student performance in the areas of planning and conducting an investigation (Cronbach Alpha .35). Items in this section of the test aimed at the identification of relevant variables, the design of an experiment, the ability to state a hypothesis, and identification of data that support a hypothesis. For the generic knowledge test as a whole a Cronbach Alpha of .85 was determined.

Cronbach's Alpha for the combined test is higher than the Alphas for the separate test sections. This can be explained by the fact that the combination of sections leads to a test with more items, adding items to a test can have a positive influence on the reliability of a test (Spearman 1910; Brown 1910). The alpha of the generic skills section is quite low. A more detailed analysis of the items and the students' scores shows that the low alpha is due to a low variation between subjects. The sum of squares of the between subject variation is 6.24 with 27 degrees of freedom.

Pearson correlations between the different test sections suggest that the three measures have a common basis. The Pearson correlation between the sections on discovery learning skills and mathematical skills was quite high ($r = .83, p < .05$), the Pearson correlation between discovery skills and graphing skills yielded ($r = .56, p < .05$), and the correlation between the section on mathematical skills and graphing skills reached ($r = .71$, $p < .05$). The fact that the different sections were highly correlated and that a combination of these sections resulted in a higher reliability, led us to combine the different sections into one test score expressing the generic knowledge of students.

The correlation of the average mark students received on science test administered by their teacher (referred to as teacher's grading) and the definitional knowledge pre-test was high ($r = .85$, $p < .001$). The same can be said about the correlation between the teacher's grading and students' scores on the generic knowledge test ($r = .86$, $p < .001$) and the correlation between the definitional and generic knowledge test ($r = .86$, $p < .001$). No significant relations between scores on the tests (generic and the definitional knowledge test) and gender were found. This implies that there is no need to correct for these variables when examining the test scores.

Proposition test

To assess students' judgments of the truth-value of propositions in the domain a proposition test was developed. In this test the students were confronted with 26 different propositions. Along with each proposition three questions were asked. First, students had to decide whether they were familiar with the proposition. Second, students had to indicate whether they thought the proposition was true, possibly true, possibly false, or false. Finally, they had to decide if they considered the proposition worthwhile to test. The answers given to these three questions were used to determine the configuration of the extended SDDS model for each student. The propositions test was administered as a paper and pencil test.

2.2.5 Communication and interaction

During the learning session students communicated face to face. Within the study described in this paper we used the verbal interactions between students as a window on the students' discovery learning processes (Webb, 1991). All verbal interaction was recorded, transcribed and coded in a stepwise manner. All actions that students performed within the learning environment were logged. From the log-files we derived information about the time students spent in a certain level and the type and number of assignments they made.

2.2.6 Coding and scoring

The transcribed protocols were coded in a stepwise manner. The coding scheme was based on the different discovery learning processes distinguished by Njoo and de Jong (1993) and the analysis of a number of interaction protocols from a pilot session. First, all the dialogues were segmented into utterances. An utterance is defined as a series of words that has one single communicative function; it is a distinct message from one student to another or from the student to him or herself. Second, each utterance was categorized as on- or off-task communication. Off-task communication was not further categorized. Third, on-task communication was further categorized as technical, regulative, or transformative. All utterances related to technical features of the learning environment, for instance closing and opening an assignment or window, were coded as technical. Utterances related to planning or monitoring of the learning process were coded as regulative. Communication that directly yielded knowledge was coded as transformative. Fourth, all communication referred to as transformative, was further analyzed. As indicated in the introduction we distinguished the following transformative processes; orientation, proposition generation, experimentation, and interpretation.

A second coder was trained to work with the coding system and coded ten percent of the data independently from the first coder. The inter-rater reliability coefficients of coding utterances in terms of on and off-task communication reached .95 (Cohen’s Kappa). Inter-rater reliability of coding utterances in terms of technical, regulative and transformative communication reached .90 (Cohen’s Kappa) and the inter-rater reliability regarding the transformative processes reached .68 (Cohen’s Kappa). The results presented in the results Section are based on the coding of the first coder.

2.2.7 Procedure

In the week before the learning sessions the students took the generic and definitional knowledge pre-tests during their physics lessons. The study was conducted over 15 sessions. Each session consisted of the withdrawal of 2 dyads from their regular physics class to participate in this study. Students were asked to complete the proposition pre-test and received a summary of the introduction.

Subsequently, students entered the introductory level of the simulation to get used to the environment. After approximately seven minutes the students were asked to leave the introductory level and start working on the learning task. Each dyad participated in one 50 minute block of interaction with the learning environment. During the session students were provided with a short description of the program on paper. The description covered the issues addressed during the introduction. Throughout the session the students were free to talk to their partner. Furthermore, students were allowed to use a calculator and make notes during the experiment. Due to technical difficulties one of the dyads was not able to complete the entire learning session. The results of this dyad are not used in the results section.

2.3 Results

First, we provide a brief overview of students' communication. Second, we report on the relations between the knowledge tests and students' communication regarding discovery learning processes. Finally, we will use excerpts from the students' dialogues to highlight students' development of knowledge configurations during the collaborative discovery learning session.

2.3.1 Analysis of communication

During the learning sessions, we recorded all verbal interactions, 28 students in 14 dyads made a total number of 4358 utterances. The number of utterances dyads made ranged from a minimum of 138 utterances to a maximum of 486 utterances. Protocol analyses revealed that utterances of each partner in a dyad were fairly equitable with an average of 47.8 percent to 52.2 percent (SD = 1.67).

The fact that both members of a dyad contributed an almost equal number of utterances to the dialogue in combination with the qualitative analysis of the protocols suggested that turn taking was present during the collaborative discovery learning process.

In Table 2-1 we present an overview of on-task and off-task communication and the different categories of on-task communication. The percentage of off-task communication is 6.7 percent, which can be considered as low. Examination of the protocols showed that off-task communication mostly appeared at the beginning and end of a learning session. Examples of off-task communication are statements such as giving compliments and school-related topics like the lesson plan. Of all utterances 2.1 percent is related to technical problems students experienced in the environment.

All remarks related to planning or monitoring were coded as regulative. About 16 percent of all the remarks made by the students can be called regulative. Most of these remarks occurred at the beginning of the session after the students had introduced themselves, and when they had to choose a new assignment or experiment. Other regulative remarks were made after students had experienced (technical) problems or made some off-task remarks. It seemed that technical problems as well as off-task talking disturbed the discovery learning process and that the students had to recover from that disturbance by (re)stating their plans.

Table 2-1, shows that 74.8 percent of the on-task communication was related to transformative processes. All utterances directly related to the domain of the learning environment, the experiment, assignment, or problem within the environment that the student worked on was coded as a transformative process.

Table 2-1. Overview of types of communication in frequencies and percentages (Note: N= 14 dyads.)

Category	Sub-category	Frequency	Percentage	Standard deviation
Off-task		292	6.7	8.08
On-task	Technical	91	2.1	2.20
	Regulative	716	16.4	12.05
	Transformative	3259	74.8	41.01
Total		4358	100.0	

2.3.2 Learning processes

Students' transformative communication was analyzed in terms of the discovery learning processes. We distinguished four processes based on a model designed by Njoo and de Jong (1993). The processes distinguished are orientation, proposition generation, experimentation, and interpretation. A detailed description of these processes can be found in Chapter 1. Table 2-2, indicates that the majority of transformative utterances were related to orientation.

This means that students made many exploratory remarks about the domain and the learning environment. It seems logical that a large percentage of utterances were devoted to orientation. Especially when students began working with the learning environment they felt the need to explore the possibilities of the environment and shared ideas about it. Only a small amount of utterances were related to proposition generation.

Table 2-2. Frequencies, percentages, and standard deviations of transformative processes

Learning process	Frequencies	Percentage of transformative processes	Standard deviation
Orientation	2285	70.1	26.33
Proposition	39	1.2	2.69
Experiment	556	17.1	10.62
Interpretation	379	11.6	8.84
Total	3259	100	

2.3.3 Prior knowledge interaction and knowledge construction

In order to investigate the influence of prior knowledge on the students discovery learning behavior we computed the partial correlation (controlling for the total number of utterances) between the number of on-task, off-task, regulative and, transformative utterances of individual students with their scores on the different prior knowledge tests. We found significant negative correlations between the amount of technical utterances made by the students and their scores on the definitional knowledge test (r =-.50, p<.05), the generic knowledge test (r = -.57, p<.05) and the combination of the tests (r = -.56, p<.05). The results suggest that students with lower pre-test scores made more remarks about the technical aspects of the simulation. The majority of technical remarks referred to problems students experienced using the learning environment. Roth, Woszczyna and Smith (1996) describe that operating the software can distract students from the content that they are supposed to learn. The results of our study suggest that low achieving students experienced more trouble operating the system than high achievers. However, the percentage of utterances regarding technical issues was still relatively small (2.1 percent of the total number of utterances, see Table 2-1).

Utterances related to transformative processes were further classified in terms of the following processes; orientation, proposition, experiment, and interpretation. To examine the relation between prior knowledge and the number of utterances that were coded into one of the transformative processes, we used a partial correlation controlling for the total number of utterances.

We found a significant correlation ($r = .34$, $p < .05$) between scores on the definitional prior knowledge test and the amount of communication related to interpretation of data. Other correlations were not significant. The results might indicate that definitional knowledge helped students to make sense of experimental outcomes.

We further investigated the influence of prior knowledge, from the perspective of differences in prior knowledge between the two students in a dyad. This means that the results presented focus on the scores and performances of dyads instead of individual students. For each dyad we calculated the “score” difference between the partners on the generic knowledge test, the definitional knowledge test, and the combination of these two tests. The score difference of one pair of students differed more than two standard deviations from the average score difference. The pair consisted of an extreme high and an extreme low achieving student. This pair of students was considered as on outlier and their score difference was excluded from further analyses, leaving 13 dyads in the analyses. However, in the qualitative analysis we take a closer look at the learning session of this particular dyad. The score differences were correlated with the number of utterances coded as one of the transformative processes, corrected for the total number of utterances. We found positive and significant relations between the score difference on the generic knowledge test and the number of utterances dyads made related to proposition generation ($r = .58$, $p < .05$) and the design and execution of experiments ($r = .67$, $p < .05$). Dyads consisting of students with a different level of generic prior knowledge produced more utterances related to proposition generation and to experimentation. Furthermore, positive relations were found between the amount of utterances related to experimentation and the score difference on the definitional test (*r* =.70, *p*<.05) and the combination of both tests (*r* =.78, *p*<.05). This suggests that heterogeneity supports talk about hypotheses and experiments. The fact that the score difference on the generic prior knowledge test and proposition generation are positively correlated suggests that heterogeneity with respect to generic skills stimulates the generation of hypotheses. The close to significant negative relation of the score difference on the generic knowledge test and the number of utterances made in the orientation category suggests that dyads that are more homogeneous with respect to generic skills, perform more orientating processes. Examination of the protocols showed that these dyads searched for extra information on variables and relations in the simulation environment.

Examination of the test-scores showed that almost all homogeneous dyads consisted of students with low or average scores on the prior knowledge test. No homogenous high achieving dyads participated in the experiment. Combined with the negative correlation between orientation and generic skills and the significant positive correlation between proposition generation and experimentation this might indicate that low and average achieving students in homogeneous dyads share the same limited resources that keep these dyads from stating hypotheses and experimenting.

2.3.4 Behavior within the simulation

Log files provided us with information about the dyads' behavior. We used the number of simulation runs and the number of assignments dyads completed successfully as an indicator of their behavior in the simulation. During the learning session each dyad shared a computer. The number of assignments students completed successfully was positively correlated with the score difference between partners' scores on the definitional knowledge test (*r* =.62, p<.05) and the combination of definitional knowledge and generic knowledge (*r* =.60, p<.05).

One could argue that within a heterogeneous dyad the higher achieving student could be the one solving the problem on his or her own. However, we found that in our sample both partners contributed about the same amount of utterances to a dialogue. This and the fact that the proportion of off-task utterances was rather small suggest that both partners were involved in on- task behavior.

2.3.5 Discovery learning processes and knowledge development

In this Section two excerpts from protocols are used to describe the students' knowledge development. The knowledge development of the two dyads is described in terms of the extended SDDS model. The initial knowledge configurations are based on students' scores on the prior knowledge tests (definitional, generic, and proposition).

In the first excerpt the dialogue of two average achieving students (Judith and Simone) is analyzed. The prior knowledge base of Judith and Simone is similar. In the second excerpt we take a closer look at the dialogue between Inge and Arjan. Inge performed very well on the pre-tests and Arjan scored very low. Because of the large difference between the pre-test scores of Inge and Arjan, their score difference was not statically analyzed. In this section we explore their collaborative discovery learning process.

Judith and Simone

In this episode Judith and Simone are working on the second level of the simulation. The central formula within this level of the simulation environment is $s(t) = v\ (0)\ .\ t + 0{,}5 \cdot a \cdot t^2$. Judith and Simone are both average achievers according to their test results. Their learner domain spaces have a little overlap with the target conceptual model. Simone and Judith have some prior knowledge in common and share a few misconceptions. Their score difference (combination generic and domain) was 4 points.

Table 2-3. Episode from the transcribed discourse of Judith and Simone

Turn	Student	Transcribed discourse
1	Judith	I don't get this one either.
2	Judith	What about acceleration, this formula.
3	Simone	Has nothing to do with this.
4	Judith	Do we have to do something with a formula
5	Simone	I don't get this one either
6	Judith	We can't solve it.
7	Judith	We can't spend all our time on this problem.
8	Judith	Let's go to level 3
9	Simone	No this was hard enough, already
10	Simone	Let's do one over here.
11	Simone	Estimate the distance covered

12	Judith	Moped is starting from standstill.
13	Judith	After 10 seconds…..
14	Simone	It has covered 5 meters.
15	Judith	I think we start with 0.5
16	Simone	Formula?
17	Judith	$s(t) = 0{,}5\cdot 0.5\ a \cdot t^2$
18	Simone	Is 25
19	Simone	Put the answer in there and press enter
20	Judith	Where?
21	Simone	Predicted value, over here.
22	Simone	Press enter.
23	Judith	The moped actually covers the…
24	Simone	It's ok.
25	Judith	Yeah, and the formula is over there, also
26	Simone	Let's give the other one a try.
27	Simone	Using that s (t) formula.
28	Simone	Well it's an s (t) diagram.
29	Judith	25 meters is the distance covered, we were using a v (t) formula al the time.
30	Simone	$s(t) = 0{,}5 \cdot a \cdot t^2$
31	Judith	Than the acceleration should be 2 meter.
32	Simone	Look that formula was also used in the estimation assignment
33	Simone	It must be time or something?
34	Simone	Yeah we have to close.
35	Judith	We get something.

Before the episode transcribed in Table 2-3, Simone and Judith worked a while on the following problem: "What is the acceleration of your moped when you cover a distance of 25 meters in 5 seconds and start from a standstill. Calculate the acceleration." Simone and Judith tried solving this problem without using a formula for distance covered. They didn't succeed.

We can say that Simone and Judith both lacked the knowledge needed to solve the assignment. Simone and Judith both do not know that they should use a formula that includes the distance covered. They make another attempt and start by looking up formulas within the program. In turn 1, 2, 3, and 4 Simone and Judith try to find additional information in the learning environment, since they both do not know how to solve the assignment.

Simone asks what the formula with “half a” in it means. This actually is the formula the students have to use to solve this assignment. Both Simone and Judith do not recognize the formula as a relevant formula for the present assignment (see turn 2, 3, and 4). They know of the existence of the formula but they don’t consider it relevant for the assignment they’re working on. This implies that this formula is located within the proposition space of both students but outside their domain spaces. Simone and Judith decide that they have spent enough time on this particular assignment and start a new assignment. In this assignment they have to estimate the covered distance of a moped. In the assignment they use a formula including covered distance and are able to solve the problem. They get back to the former problem and Simone suggests that they should use the s (t) formula instead of the v (t) formulas they have used before. She strengthens her suggestion by referring to the s (t) diagram that is used in the simulation (turn 27 and 28). The formula becomes relevant to Simone and thus becomes part of her learner domain space. Judith notices that the 25 meters in the assignment actually refer to the distance covered and now she also thinks it makes sense to use the following formula: $s(t) = v(0) . t + 0,5 . a . t^2$ and she adds another reason as shown in turn 29. Because Judith is also considering the formula it becomes part of her learner domain space too.

Within the dialogue between Simone and Judith we can distinguish different phases. The prior knowledge of Simone and Judith regarding the assignment they are doing is quite similar. Therefore, the partners are not likely to assist each other with explanations or additional information. Earlier, we presented data that suggested that students with a similar knowledge base spent a higher proportion of their communication on orientation. New information must be obtained from another source. Simone and Judith start looking in the learning environment for a formula that might give them a clue. They do not recognize the relevant formula and decide to make another assignment (regulative process). In turn 15 they start an experiment. The results of this experiment influence their behavior. They decide to go back to the other assignment. Simone relates the results of the previous assignment to the present assignment and suggests that they should use the formula for covered distance. She is presenting a new idea to her partner. They decide to perform the experiment and discuss the results. The results confirm Simone's suggestions.

In this excerpt Simone and Judith use the environment as reference material. In turn 17 Judith refers to a formula she found in the simulation environment. In turn 23 Judith refers to the simulation. The animated moped is moving and the graph is changing. Simone (turn 28) is talking about the diagram. Judith and Simone use the environment to solve problems and create meaning. Sharing tables, graphs and other reference material can promote learning. Moschkovich (1996) describes the peer discussion of students talking about the lines on a computer screen. She finds that sharing references materials like the graphs on the computer is an important aspect of the negotiation of meaning. If we look from the perspective of Newman, Griffin and Cole (1989) students can not only support each other, but tools can also be part of the supportive structure. A simulation can assist students' interaction during science learning (Roth, 1995). In the case of Judith and Simone the simulation and the graph illustrates the phenomena under discussion, the students refer to the graph in their reasoning process.

Inge and Arjan

In Table 2-4, the conversation between Arjan and Inge is transcribed. The score difference between Inge and Arjans' pre-test scores is rather large. Inge and Arjan were excluded from the quantitative analyses because their score difference, differed more than two standard deviations from the mean. They differed 26 points from each other (generic and domain) Inge performed very well on the test. Her learner domain space has a lot of overlaps with the target conceptual model. Arjan scored low on the pre-test. His learner domain space has only a little overlap with the target conceptual model.

Arjan and Inge have to calculate the acceleration of a motorbike. The motorbike was traveling at a velocity of 108 kilometers an hour and has to reach standstill in 90 meters to avoid a collision. If the motorbike slows down too quickly the bike will skid, if it doesn't brake hard enough it will collide. Inge and Arjan are already working together for 20 minutes when they open this assignment. Most of the time Inge is calculating and explaining the assignments to Arjan. Arjan finds it difficult to understand her reasoning. In the first level he is able to understand the major part of Inge's explanations, but now he is experiencing serious problems.

Table 2-4. Episode from the transcribed discourse of Inge and Arjan

Turn	Student	Transcribed discourse
1	Inge	Let's go to the next assignment.
2	Arjan	That skidding assignment is cool, don't you agree?
3	Inge	Initial speed is 30. Look they filled it in, over here.
4	Arjan	Well we have 90 meter
5	Inge	Yeah and we are driving 108 kilometer an hour
6	Arjan	So what are we supposed to do next?
7	Inge	Brake
8	Inge	The acceleration must be negative
9	Inge	We have to calculate the acceleration
10	Arjan	So?
11	Inge	Maybe we can start with the same formula we used before.
12	Inge	You have 90 meters, so that could be your covered distance.108 kilometers an hour equals 30 meter a second. We don't know the time.
13	Arjan	Well fine, we still only know three out of the six terms in the formula.
14	Inge	Well maybe we can find these terms
15	Arjan	Give it try.
16	Inge	We have to find it
17	Arjan	Fine.
18	Inge	Let's take a look at this.
19	Inge	The final speed has to be zero, because you have to reach standstill.
20	Inge	That means we have a final speed of zero v (t) equals zero
21	Inge	Shall we continue calling 30 the initial speed?
22	Arjan	Fine with me.
23	Inge	Final speed is zero and initial speed 30, plus acceleration times t
24	Inge	I think that t equals 30 divided by acceleration.
25	Arjan	So that helps, us a lot. (Sarcastic)
26	Inge	Sstt, let me try.

27	Inge	Here we go, $90 =30+30/a + 5 \cdot a(30/a)$
28	Inge	Let’s calculate.
29	Arjan	Gee, what a fuss
30	Arjan	We really are supposed to think.
31	Inge	I think it should be -5
32	Arjan	Try it?
33	Arjan	It’s correct
34	Inge	Gee, you’re the greatest.

At the beginning it is not exactly clear to Inge how she should calculate the right answer, but she knows a lot of concepts and two formulas that she can use (turns 12, 13, 14, and 27). And she decides to try (turn 28) them. All the formulas, relations and concepts Inge needs to solve this problem are located within her learner domain space. Arjan doesn’t share the large knowledge base Inge has. He does not exactly know when to use a certain formula and is insecure about the meaning of concepts. This is reflected in the conversation. Arjan does not ask questions and does not contribute to the learning process anymore. His job is to click and double click. He agrees with Inge’s decisions and expresses feelings of incapacity and indifference.

Inge's learner domain space and the target conceptual model almost completely overlap, in contrast to Arjan’s learner domain space that is much smaller and only covers part of the target conceptual model. Nevertheless, the procedure Inge needs to solve the assignment is not located within her learner domain space at this moment, However, Inge is familiar with the relations, variables and formulas that she needs to solve the problem. These are located within her proposition space. Inge uses her prior knowledge about the domain to tackle this new problem, and succeeds. She has learned to use the combination of the formula $s\ (t) = v\ (0) \cdot t + 0,5 \cdot a \cdot t^2$ and $v\ (t) = v\ (0) + a \cdot t$ to solve the problem and determine the missing variables. The procedure becomes a part of Inge’s learner domain space. Arjan unfortunately has less prior knowledge about the domain. He knows the two formulas stated before, but experiences difficulties when he has to apply them. As a result of some remarks that Arjan makes during the rest of the session there are serious reasons to believe that he still has difficulties with the application of formulas and that the procedure did not become part of his learner domain space. After the learning session, the procedure has become part of Inge’s learner domain space. Arjan’s learner domain space still does not include the procedure, but it has become part of his hypothesis space. This means that he now knows that a procedure like this exists but that he is not able to apply it.

The protocol of Inge and Arjan illustrates that roles are changing during the collaborative discovery learning process. In the episode transcribed in Table 2-4, Arjan has serious troubles following Inge’s actions and explanations. Arjan still communicates with Inge but his utterances do not contribute to the transformative processes anymore. In the beginning of the same session Arjan was able to follow Inge's reasoning and made some assignments himself. During the learning session, assignments got more complex and in contrast to Inge, Arjan was not able to handle this complexity.

In this case the proposition under discussion is located in the learner hypothesis space of the more capable peer and located outside the domain space and learner hypothesis space of the less capable peer. In order to assist Arjan a major tutoring task is waiting for Inge.

In this situation the less capable peer (Arjan) is not familiar with the variables and relations Inge uses. We could say that in this case the proposition is probably not in the zone of proximal development of Arjan. The differences in prior knowledge between the two collaborating students are too large.

2.4 Discussion

In this study we have examined the relation between prior knowledge and collaborative discovery learning for dyads of students working together within the same learning environment. This is a potentially interesting learning scenario because the knowledge of the collaborating students can exceed the knowledge of both individual students (see e.g., Dillenbourg, 1999). Collaboration offers possibilities for co-construction of knowledge, comparison of alternative viewpoints, explication of plans, concepts and ideas. Explication of ideas can induce cognitive conflicts which might facilitate cognitive change (Chan, 2001).

The results of this study suggest that group composition in terms of prior knowledge is related to discovery learning processes. Our results show that heterogeneous pairs talked relatively more about different propositions and the carrying out of experiments. The conversation of the more homogenous low and average achieving dyads is more related to orientation processes. These pairs of students try to fill in their knowledge gaps by orientation in the environment. Homogenous groups with low or average achieving students who share the same limited knowledge resources and misconceptions are more likely to experience difficulties creating a meaningful conversation and constructing new knowledge.

In a heterogeneous group the student with more prior knowledge can serve as a guide for the less capable peer. The low achiever learns from the explanations given by the high achiever and high achievers have to restructure their knowledge in order to give appropriate help. This restructuring helps the explainer to understand the material better. From this perspective, heterogeneous grouping is beneficial for both the high and the low achieving students (Webb, Welner, & Zuniga, 2001).

However, the qualitative analysis of Inge and Arjan in our study suggests that extreme knowledge differences within a dyad lead to frustrating situations. At the end of the learning session Inge is solving the problems by herself and has stopped explaining the problems to Arjan. The complexity of the problems Inge tackles at the end of the learning session is quite high. The concepts and formulae Inge uses to solve the problem are quite new or even unfamiliar to Arjan. He does not understand Inge’s reasoning. In the case of Inge and Arjan we can observe that Inge is not functioning in Arjan’s zone of proximal development and does not respond to the problems he is experiencing. Webb, Welner, and Zuniga (2001) distinguish between high ability students that perform low in heterogeneous groups and high ability students that perform high in heterogeneous group. High ability students that perform low in heterogeneous groups do not respond to help seeking group members with elaborated explanations. For example they might solve the problem without providing further information, or even insult the person who is seeking help. In a well functioning group low ability students might actively search for help, and benefit from explanations by applying them to a similar problem.

Extra information about the domain is important for both homogeneous low or average achieving dyads and dyads with extreme differences between the students. In the case of Inge and

Arjan it became clear that Arjan lacked domain knowledge, and could not keep up with Inge. When using collaborative discovery in a classroom context it is important that teachers observe the group processes and interfere when necessary. For example by providing hints or pairing students in different groups.

Collaborative discovery learning can offer some unique opportunities for learning. Interaction with the simulation environment allows students to experiment within the phenomena in the domain and discuss these with their partner. Simulations can be coordinated with other instructional activities. For example experiences within the environment, and elements of the discussion between peers, can be discussed in the classroom. Furthermore, observation of students' behavior in the collaborative discovery learning setting can provide teachers valuable information on students' ideas and misconceptions in the domain.

The study indicates that it is important that students become aware of and discuss the differences between their own beliefs, concepts or theories, and new information. Collaboration is one way to confront students with the beliefs of others. However, students in a collaborative discovery learning setting are not always aware of their knowledge gaps and initial differences. De Vries, Lund and Baker (2002) argue that computer learning environments should be carefully engineered to stimulate discussion and provide the opportunity to support and guide students' activities and communication. One way to take this into account would be to redesign the learning environment in such a way that students with initial differences become aware of each others beliefs. For example by assessing students' individual opinions about a number of propositions in the domain and combining them into a shared table that visualizes the opinions of both partners. The externalization of students' individual opinions might stimulate the discussion of alternative conceptions which might lead to the refinement of students' knowledge and eventually cognitive change.

3. Sharing and confronting propositions in collaborative scientific discovery learning

Abstract

This study investigates how collaborative knowledge construction within a discovery learning environment can be assisted with tools that aim to support students' proposition generation and testing processes. Sixty-six fourth year pre-university education students participated in a kinematics learning task. The instructional goal of the learning activity was to develop students' understanding of one dimensional kinematics. The activity focused on collaborative inquiry. All students completed a proposition list in which they could indicate their individual opinion about the truth-value of specific propositions. Subsequently, students were coupled into dyads and assigned to one of three conditions: 1) an expression builder (scratchpad), 2) a shared propositions table and 3) a control condition. Students in the scratchpad condition were provided with an expression builder consisting of dropdown menus with variables and relations. The shared proposition table combined students' individual opinions about the truth-value of a proposition into one shared proposition table that visualized differences in opinion. Students in the control condition received no extra support related to propositions. Learning outcomes were assessed using an intuitive knowledge pre- and post-test. The findings indicate that students supported with the shared proposition table improved significantly from pre- to post-test and discussed significantly more alternative propositions.

3.1 Introduction

Scientific discovery learning in simulation environments is a highly self-directed way of learning that is especially suited for constructivist forms of learning (de Jong & van Joolingen, 1998). Within such a learning environment students try to find characteristics of the model underlying the simulation through experimentation (Friedler et al., 1990). Swaak and de Jong (1996) hypothesize that knowledge that students obtain in discovery learning environments has a more intuitive character and is better anchored than knowledge that is gained from traditional lectures.

Besides having advantages, scientific discovery learning is generally recognized as a difficult process for students. Research shows that students are not always capable to direct their own learning processes and find it difficult to induce information from a simulation environment. Various instructional measures and tools have been developed to overcome the problems that students experience during the discovery learning process (de Jong & van Joolingen, 1998). These tools mostly have been developed for discovery by individual students. However, instead of or in addition to individual tools, collaboration with another student might be a natural way of support during discovery learning. In a collaborative setting plans have to be made explicit and the construction of knowledge (reasoning, theories, and ideas) has to be explained in a way that is understandable for the partners in the collaborative learning group (Teasley, 1995). This collaborative process, however, also needs support (Fischer, Bruhn, Gräsel, & Mandl, 2002; Soller, 2004).

In this study, we concentrate on supporting collaborative discovery learning with computer simulations. We describe tools that are designed to stimulate meaningful interaction between students and that support them during the discovery learning process.

3.1.1 Collaborative discovery learning

Collaborative learning and discovery learning both are active approaches towards learning. In collaborative discovery learning students are expected to co-construct knowledge based on prior knowledge and the information available in the learning environment. Several different classification schemes are used to study discovery learning processes(see e.g., Kuhn et al., 2000; Njoo & de Jong, 1993;

White et al., 1999). In this study the classification scheme of Njoo and de Jong (1993) is followed. Njoo and de Jong (1993) distinguish between regulative and transformative processes. Regulative processes are those processes that focus on planning and monitoring of the learning process. Transformative processes directly yield knowledge. In our research project we further classify transformative processes into: *orientation, proposition generation*, *experimentation*, and *interpretation.* During orientation students identify the variables and parameters in the model and indicate the general properties of the model. Orientation can be done on the basis of the students' own prior knowledge, the knowledge of the partner, the use of additional information, and the information available in the simulation environment. In the orientation phase students form an idea of the structure and the complexity of the domain at hand.

Generating propositions is one of the central processes in discovery learning. In a proposition students specify the relation between input and output variables. By stating, accepting, rejecting and/or refining propositions students build a mental model of the domain. Generating a proposition is a difficult process. Students for example may experience difficulties with formulating a testable proposition and they often stick to their initial proposition because they are unable to think of an alternative proposition.

In order to collect information about the truth-value of a proposition students perform experiments. Students might experience difficulties with the translation of a proposition into an experiment. Schauble, Glaser, Raghavan, and Reiner (1991) found that students sometimes perform experiments that are not suited to test the intended proposition.

Once students have performed an experiment, the data from the experiment needs to be interpreted. Simulation based learning environment offer the possibility to present experimental output in various forms like graphs, animations, and numerical data. This means that during the interpretation phase students can interpret numerical and graphical information, and compare the results of different experiments. Students often make mistakes interpreting experimental outcomes represented in graphs or tables (Beichner, 1994; de Jong & van Joolingen, 1998)

Not only the transformative processes but also the regulative processes may be problematic and may be supported in a collaborative setting. Various studies have shown that successful students plan their experiments and pay significantly more attention to data-management (Schauble et al., 1991; Shute & Glaser, 1990). However, many students tend to plan only locally, and do not take their prior experiments into account.

Combining discovery learning and collaborative learning is a promising approach to help students to overcome problems that they encounter. The problem, for example, that learners have to come up with testable propositions can be resolved in collaborative learning settings by being confronted with alternative propositions from fellow learners. Okada and Simon (1997) compared the collaborative discovery learning of pairs of students with single students. They found that the paired students considered more alternative ideas and conducted more informative experiments; the generation of alternative ideas was often triggered by a question or remark of the partner.

The collaborative learning setting stimulates students to communicate about their ideas and activities in a way that is understandable for their partner (Damon & Phelps, 1989). A lack in the prior knowledge base of one student might be filled in be the prior knowledge of another student. Furthermore, confrontation with contradicting beliefs might induce a socio-cognitive conflict which stimulates the student to reflect on their own beliefs (Doise, Mugny, & Perez, 1998).

3.1.2 Interactions between students during collaborative discovery learning

In a previous study (Gijlers & de Jong, 2005) we examined the collaborative discovery learning behavior of students. In this study dyads of students worked together on a discovery learning task, in a face to face setting. The verbal interactions of these students were transcribed and scored. Students' on-task communication was analyzed in terms of technical, regulative, and transformative communication. Different tests were used to assess the different kinds of prior knowledge and to determine students' knowledge configurations. A definitional knowledge test was used to assess students' knowledge of concepts and variables in the domain. A generic knowledge test focused more on students' ability to work with mathematical relations, such as their ability to interpret graphs and experimental outcomes and their discovery skills.

The results of this study suggested that difference in opinion might stimulate the students' communication about the design of an experiment and the interpretation of experimental data. More homogeneous dyads produced a greater proportion of talk related to the orientation phase. Heterogeneous dyads generated more propositions during their interaction than homogeneous dyads. Furthermore, heterogeneous couples talked significantly more about the execution of experiments. Nonetheless, the amount of talk related to these phases was rather small. The fact that students did not extensively discuss propositions with each other is troublesome. We emphasized before that proposition generation is an important phase in the discovery learning process. Shute and Glaser (1990) found that students who performed a proposition driven experiment were more successful than their peers who used a more experimental approach. The first group of students worked more systematically, used more powerful heuristics and showed higher level planning.

Two explanations for the fact that students did not discuss different propositions with each other are offered. The first possible explanation focuses on the fact that student find it difficult to state a relation between variables. The second explanation is that propositions are not (fully) verbalized and students therefore are not aware of the fact that their partner holds different beliefs (de Vries, Lund, & Baker, 2002).

In order to benefit from a partners' alternative beliefs students have to be aware of the differences in their ideas (de Vries et al., 2002). De Vries et al. continue that the learning setting should be carefully engineered to stimulate epistemic discussion. Learning tasks can be arranged in such a way that different points of view are possible, visible and can easily be confronted (Reiser, 2004). Nastasi and Clements (1992) state that the articulation of one's own perspective and willingness to discuss this perspective with others can foster conceptual change. Limón (2001) states that there are various methods to induce a cognitive conflict such as the introduction of contradictionary information. Limón (2001) suggests that cognitive conflicts are likely to foster conceptual change. Nastasi and Clements (1992) explain that the socio-cognitive conflict in itself is not the most important when it comes to positive influences on learning outcomes. The processes that lead to the solution of the conflict mediate the effects on the learning outcomes. Reflection on different viewpoints and discussion about concepts and ideas are considered beneficial for the learning process.

All in all it seems to be important that individual students become aware of and discuss the differences between each others' conceptions, theories, and new information. Collaboration is one way to confront students with the beliefs of others. In Gijlers and de Jong (2005) we found that too few propositions were verbalized and therefore, students possibly where not fully aware of the fact that their partner held different ideas. This decreases the likelihood that a profound discussion about different ideas will arise. Because the generation of propositions is such a crucial phase in the whole discovery learning process and the discussion of alternative propositions within dyads might lead to the explication of differences in prior beliefs we think it is important to support propositions generation and the discussion about propositions.

3.1.3 Supporting proposition generation

Computer supported learning environments provide the opportunity to support and guide students' activities and communication, and create conditions for (socio) cognitive conflicts. The discussion about propositions can be supported in more or less directive ways. Supporting the students by prompting them to state a proposition is the least directive intervention. Providing students with so-called expression builders is a more directive form of support. Within an expression builder students are offered windows or menu's where they can select basic phrases like: 'if', 'then', 'and', and, 'when'. The expression builder can help students state a relation between variables. Students can insert variables, relations and/or conditions to the basic phrases (van Joolingen & de Jong, 1991). The most directive way is to present the student with pre-defined propositions. When students are confronted with a list of predefined propositions they can choose which proposition from the list they consider worthwhile testing. Providing students with predefined propositions allows the designer to point students in the direction of important concepts and mechanisms in the domain and influence the quality of the propositions that will be tested. Njoo and de Jong (1993) showed that providing the students with predefined propositions has a positive effect on the global activity of the student. The study also showed that students choose different routes through the list of propositions and none of these routes was strongly favored. This suggests that offering students a list of predefined propositions still leaves freedom to explore.

The tools designed by van Joolingen and de Jong (1991, 1993) and Njoo and de Jong (1993) can also be used in collaborative learning settings. Providing students with a proposition scratchpad and asking them to build propositions together and is expect to help students maintaining a common focus and stimulate the discussion about different combinations of variables and relations. Providing students with predefined propositions can also stimulate students to maintain a common focus and discuss propositions within the domain. Furthermore, by providing students with predefined propositions it can be assured that the propositions the students work with are syntactically correct and can be tested with the simulations available in the learning environment.

In the present study we report on the evaluation of two different tools, in the context of a simulation based discovery environment, that are designed to support dyads of students during their discovery learning process. More specifically, the tools focus on the proposition generation process by providing the students with a proposition scratchpad (an expression builder) or by giving them predefined propositions. Students in a control condition did not receive extra support on proposition generation.

3.2 Method

3.2.1 Domain and Learning environment

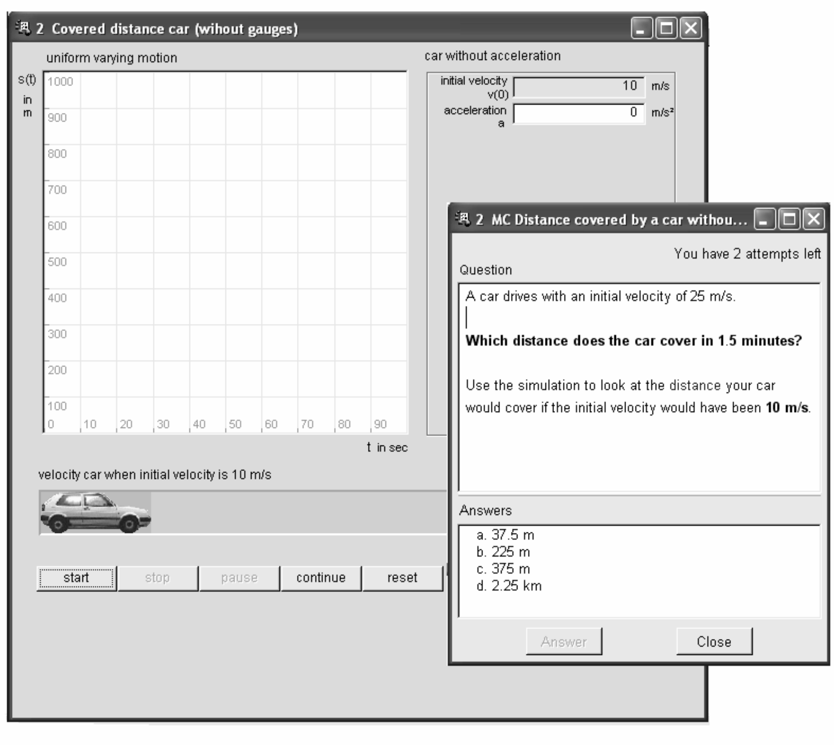
The learning environment in this study concerned the physics domain of kinematics. The domain of kinematics is prone to misconceptions. The misconceptions of students are grounded in extensive personal experiences and instruction (Halloun & Hestenes, 1985a). Computer simulations can address some of the problems students' experience in the domain of kinematics. The animation of motion combined with a graph can help students understand kinematical graphs.

Within the simulation environment students were able to change numbers of input variables and observe the behavior of output variables. The students were not exposed to the full complexity of the underlying model at once. Model progression (White & Frederiksen, 1990) was used to divide the domain into three levels. Learners were free to start at any level, and move back and forth between the levels.

The model in the, first, level focused on initial velocity, acceleration, time and final velocity ($v(t) = v(0) + a \cdot t$). The relevant variables were presented to the student one at a time. In the first progression level students could test propositions such as: “if the acceleration of a car equals zero than the final velocity of this car will equal the initial velocity”. Within the second progression level the students worked with simulations on distance covered. In the third, and final, progression level the concepts mass and friction were introduced to the students. After the introductory level learners were free to start at any level and move back and forth between them.

Thirty five assignments were used to guide students through the key elements of the simulation and provide them with short-term goals. Together with model progression, assignments disaggregated the complex model into smaller portions.

Figure 3-1 provides an example from the learning environment. At the top left the simulation of a motorbike is shown, students can manipulate initial velocity, friction, and mass and run the simulation. At the right an example assignment is shown.



2 Covered distance car (wihout gauges)

car without acceleration

initial velocity v(0): 10 m/s

acceleration a: 0 m/s²

velocity car when initial velocity is 10 m/s

2 MC Distance covered by a car withou...

You have 2 attempts left

Question

A car drives with an initial velocity of 25 m/s.

Which distance does the car cover in 1.5 minutes?

Use the simulation to look at the distance your car would cover if the initial velocity would have been **10 m/s**.

Answers

a. 37.5 m
b. 225 m
c. 375 m
d. 2.25 km

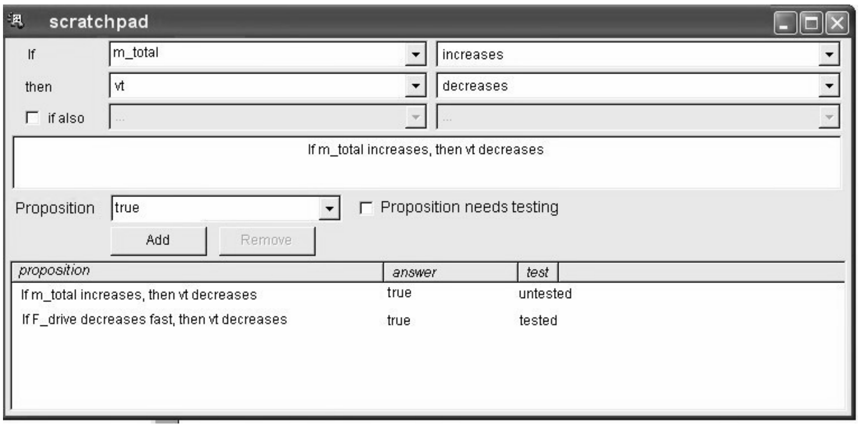
Figure 3-1. Screenshot of a simulation with an assignment

3.2.2 Tools

For the purpose of this study two tools were developed. The first tool was an expression builder based on the proposition scratchpad developed by van Joolingen and de Jong (1991). Van Joolingen and de Jong (1991) provided students with building-blocks for creating hypotheses, in the form of variables, relations, and conditions. These elements could be selected and combined by students to create hypotheses.

The proposition scratchpad in the current study had similar building blocks (relations, variables, and conditions) and was linked to the progression levels. When students entered a certain progression level the scratchpad displayed the relations, variables, and conditions, relevant in that particular level. Students were able to save the propositions they constructed. When students decided to save a proposition, they were asked to assign a truth-value to this proposition. All saved propositions were added to a list of propositions that the learner could consult during the learning process.

The proposition scratchpad was combined with a chat tool, where students for example could discuss the truth-value of a proposition. Students could test the constructed propositions with the simulation. Within each progression level students could consult three example assignments. These assignments illustrated how to construct and test a proposition. In Figure 3-2, a screenshot of the proposition scratchpad is presented.



If m_total increases
then vt decreases
☐ if also ... ...

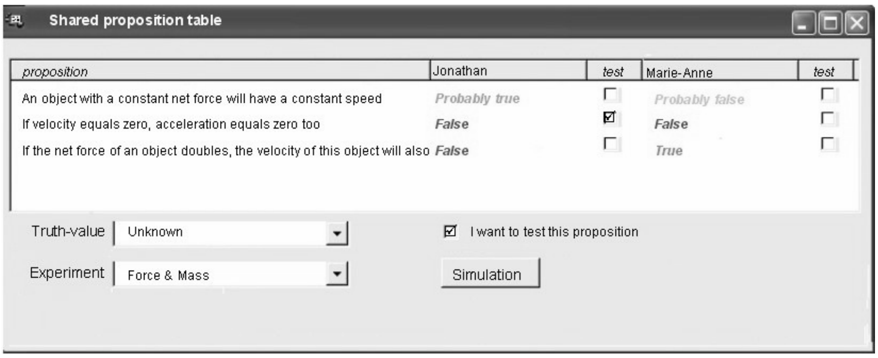
If m_total increases, then vt decreases

Proposition true
☐ Proposition needs testing

proposition	answer	test
If m_total increases, then vt decreases	true	untested
If F_drive decreases fast, then vt decreases	true	tested

Figure 3-2. Screenshot of the proposition scratchpad

The second support tool was based on the idea of predefined propositions. Each student received individually a list of propositions on the domain (the proposition test). With each proposition three questions were asked. First, the student indicated if he or she was familiar with the stated proposition, subsequently, he or she specified whether the presented proposition was true, possibly true, possibly false, or false, and, finally, it was indicated whether he or she wanted to test the proposition or not. After completing the proposition list on an individual basis, the individual proposition tables were combined into one shared proposition table, displaying the individual markings of both students (see Figure 3-3). Differences in opinion were stressed by the use of color. To facilitate communication a chat tool was added to the shared proposition table. Finally, if a dyad decided to perform an experiment for a certain proposition they could indicate this (by clicking the button ‘experiment’) and in that case they were provided with a simulation state and an assignment that was suited to test this particular proposition.



proposition	Jonathan	*test*	Marie-Anne	*test*
An object with a constant net force will have a constant speed	***Probably true***	☐	***Probably false***	☐
If velocity equals zero, acceleration equals zero too	***False***	☑	***False***	☐
If the net force of an object doubles, the velocity of this object will also	***False***	☐	***True***	☐

Truth-value: Unknown

Experiment: Force & Mass

☑ I want to test this proposition

Figure 3-3. Screenshot of a shared proposition table displaying the opinions of two students

3.2.3 Subjects

Sixty-six subjects participated in the study. They were fourth year students from secondary education, aged 15-16. All students completed an introduction in the domain of kinematics; that covered the domain knowledge needed in the simulation environment. The subjects were randomly assigned to one of the three conditions such that each condition contained 11 pairs of subjects. Subjects participated in the experiment on a voluntary basis and received a small reward for their participation. All subjects had computer experience.

3.2.4 Tests

Three test were administered, a definitional knowledge test, an intuitive knowledge test, and a proposition test. The definitional knowledge test was designed to assess students' prior definitional knowledge about the domain and was administered as a pre-test only.

Definitional knowledge test

The definitional knowledge test focused on students' definitional definitional knowledge and contained questions about concepts, formulae, and definitions that are relevant for the simulation. The test consisted of 25 (four alternative) multiple choice items. The reliability analysis of the items resulted in the removal of one item. Cronbach's alpha reached .69, which is satisfactory.

"What- if" test

Working with a discovery learning simulation is believed to produce intuitive knowledge that cannot be assessed with traditional knowledge test that focus on definitional knowledge. To assess this intuitive knowledge about the relations between variables in the domain we used a test in the so called "what-if" format (Swaak & de Jong, 1996). Each question in the "what-if" test consisted of three parts; conditions, actions and predictions. A condition is presented to the students in the form of a drawing and a short text description of the domain. The action (the change of a variable) is presented to the students in text. Finally, three predicted states are presented to the students either in text or pictures. Students are asked to select the state that follows from the action. The "what-if" test consisted of 21 items and Cronbach's alpha yielded .76 for the pre-test and .72 for the post-test which can be interpreted as good. There was no significant Pearson correlation between the results of the definitional knowledge test (pre-test only) and the "what-if" test (pre- and post). This suggests that the "what-if" test assessed a different kind of knowledge than the definitional knowledge test.

Proposition test

A proposition test focused on students' beliefs about relations within the domain. In this test 26 propositions were presented to the students. With each proposition three questions are asked. First, the students were asked whether they were familiar with the proposition or not. Second, the students had to indicate whether they thought the presented proposition were true, possibly true, possibly false, or false. Third the students indicated if they considered testing the presented proposition. The proposition test was computer administered. Students' individual responses on the proposition test were saved and used as a source of information for the shared proposition table. When a dyad started to work with the shared proposition table the truth-values individually assigned by both students were collected and combined in a shared proposition list. The proposition test was administered as a pre- and post-test. The post test version was a paper and pencil test instead of a computer administered test.

3.2.5 Procedure

Each experimental session lasted about three hours. All students followed the same sequence of events.

Introduction and pre-tests (60 minutes). The experimental session started with a short introduction to the experiment, where the researchers explained the different tests and the outline of the experimental session. Subsequently, all students individually completed the definitional knowledge pre-test, the “what-if” test, and the proposition test (computer administered).

Introduction of the environment (5 minutes). The learning environment was introduced to the students in a short presentation. During the presentation students received information needed to operate the system. A short overview of the issues addressed in this presentation was given to the student as a hand-out. Students were asked to consult this hand-out before asking questions to the experimental leaders.

Interaction with the learning environment (70 minutes). During the experiment students interacted with each other through a chat channel. Their interaction with the environment as well as the chat was logged. Two experiment leaders were available to answer questions about operating the environment. No extra information or help concerning the domain was given during the experiment. Students who indicated that they wanted to finish earlier were asked to explore the environment a bit more.

Post-tests (40 minutes). After the interaction with the environment, the post-test were administered. We started with the “what-if” post-test followed by the proposition post-test. The “what-if” test was administered electronically and the post-test version of the proposition test was a paper and pencil test.

3.2.6 Process analysis

The chat logs were coded in a stepwise manner (see also Chapter 2). First, all the dialogues were segmented into utterances. An utterance was defined as a distinct message from one student to another student or to him or herself. Second, each utterance was categorized as on- or off-task communication. Off-task communication was not further categorized. Third, on-task communication was further categorized as technical, regulative, or transformative. All utterances related to technical features of the learning environment, for instance closing and opening an assignment or window, were coded as technical. Utterances related to planning or monitoring the learning process were coded as regulative. Communication that directly yielded knowledge was coded as transformative. Fourth, all communication referred to as transformative, was further analyzed. As indicated in the introduction we distinguish the following transformative processes; orientation, proposition generation, experimentation, and interpretation. A second coder coded about 10 percent of the data. The inter-rater reliability coefficients of coding utterances in terms of on and off-task communication reached .95 (Cohen's Kappa). Inter-rater reliability of coding utterances in terms of technical, regulative, and transformative communication reached .90 (Cohen's Kappa) and the inter-rater reliability regarding the transformative processes reached .68 (Cohen's Kappa). The results presented in the results Section are based on the coding of the first coder. The learning and the chat logs were used to assess how many different propositions the students generated and discussed during their learning session.

3.3 Results

In this Section, we first report the results of the different knowledge test. Subsequently, we will give an overview of process measures, and, finally we report on the relation between the knowledge test and the interaction measures.

3.3.1 Knowledge tests

Three tests were administered; a prior definitional knowledge test, an intuitive knowledge test, and a proposition test. The definitional knowledge test was administered as a pre-test only, to determine students' prior definitional domain knowledge. The intuitive knowledge test ("what-if" test) and the proposition test were administered as both a pre- and post-test.

Prior to answering research questions, it was tested whether there were initial differences between the groups concerning prior domain and intuitive knowledge. Students were assigned randomly to the three groups, so we expected no significant differences. The results indicated that there were no significant differences (definitional knowledge: (F (2, 63) = .489, p = .616 n.s.), intuitive knowledge: (F (2, 63) = .78, p=.49 n.s.) over the three conditions.

"What-if" test

Table 3-1 gives an overview of the mean pre- and post-test scores on the "what-if" test for the three conditions. To examine whether students overall improved the "what-if" test we performed a paired sample t-test on the results of the "what-if" test. The results of this test indicate that the post-test scores on the "what-if" test were significantly better than the pre-test scores for students working with the shared proposition table ($t(21) = -6.75, p<.01$). Mean scores for students in the control and proposition scratchpad condition did not change significantly from pre- to post-test.

Table 3-1. Mean pre- and post-test scores "what-if" test for the three conditions (standard deviation between brackets)

Condition	N	Mean scores "what-if" test			
		Pre-test		Post-test	
Control condition	22	14.00	(2.00)	14.13	(1.69)
Proposition Scratchpad	22	14.50	(2.35)	14.31	(2.50)
Shared proposition table	22	13.77	(1.79)	15.22	(2.13)

To examine differences between students in the three conditions, an analysis of variance based on the students' learning gains (post-test scores minus pre-test scores) was performed. The results indicated significant differences between learning gains ($F (3, 62) = 39.10, p< .00$). The ANOVA procedure was followed up by a Tukey HSD test for multiple comparisons. The results of the Tukey HSD show that there is a significant difference between the control condition and the shared proposition table condition, and the scratchpad condition and the shared proposition table concerning the learning gains, in favor of the shared proposition table condition. No significant difference was found between the control condition and the proposition scratchpad condition. The mean post-test scores of students working with the proposition scratchpad were lower than their pre-test score, which resulted in a non-significant negative learning gain (see also Table 3- 1)

The proposition test

The proposition test was administered as a pre- and post-test. In this test, students could indicate whether or not a specific proposition was true, possibly true, possibly false or false. For the pre- and the post-test we calculated the number of propositions correctly identified as true or false. In Table 3-2 an overview of the number of correctly identified propositions is provided. A paired sample t-test revealed significant differences between pre- and post-test scores for students working with the shared proposition table. Only students in this condition significantly identified more propositions correctly on the post- test (t (21) = -6.43, *p*<.01) compared to the pre-test.

Table 3-2. Mean number of correctly identified propositions for the three conditions (standard deviation between brackets)

Condition	N	Mean number of correctly identified propositions			
		Pre-test		Post-test	
Control condition	22	9.32	(3.99)	9.77	(3.92)
Proposition Scratchpad	22	7.86	(2.87)	7.36	(3.18)
Shared proposition table	22	8.23	(3.85)	11.00	(3.40)

3.3.2 Process Measures

Students communicated with each other using the chat tool provided in the learning environment. All utterances made by the students were logged and coded using the coding scheme presented in the method Section. The students made a total of 4818 utterances during the learning session of which 98% was coded as on-task communication.

An ANOVA with as dependent variables the amount of utterances made in the various learning process categories and as independent variable the condition (control, scratchpad, or shared proposition table) was performed. No significant differences were found between the scratchpad and the shared proposition table condition for the overall number of utterances. Significant differences were found between the amount of utterances related to proposition generation (F (2, 30) = 7.41, *p*<.00). The results of a Tukey HSD multiple comparisons post hoc test indicated that students working with the proposition scratchpad and shared proposition table made significantly more remarks related to propositions than their peers in the control condition.

Inspection of chat files revealed that some students devote a large amount of utterances to one proposition or where others discuss different propositions during the learning session. From the chat protocols and the log files we got the impression that students working with the proposition scratchpad found it difficult to generate a sound proposition and discussed a single proposition in detail. Therefore, we calculated the number of unique propositions that dyads discussed during the learning session. The amount of propositions and unique propositions are presented in Table 3-3. An ANOVA with the number of unique propositions as the dependent variable revealed a significant difference between conditions (F (2, 30) = 26.82, *p*< .001).

Table 3-3. Overview or the amount of utterances, means and standard deviation for each condition (standard deviation between brackets)

Condition	N	Mean number of discussed propositions			
		All propositions		Unique propositions	
Control condition	11	3.42	(3.42)	1.09	(.34)
Proposition Scratchpad	11	14.56	(9.80)	2.82	(1.78)
Shared proposition table	11	16.85	(8.05)	7.82	(3.25)

Tukey HSD multiple comparisons post hoc test showed significant differences, concerning the mean number of unique propositions, between the shared propositions table and both other conditions. No significant differences were found between the control and the scratchpad condition. These results suggest that students in the scratchpad condition devoted more utterances to a smaller number of propositions. The scratchpad was designed to support students during the proposition generation process, but students found this a difficult process. In the scratchpad conditions the actual proposition had to be build by the students. Several choices (which variable, which relation) had to be made in order to build a proposition. This suggests that the tool is not suited to test a large number of propositions in a short learning session. Students working with the shared proposition table received a list with pre-defined propositions; they did not have to build their own proposition.

3.3.3 Knowledge and process measures related

No significant relations were found between the results of the definitional knowledge test and the percentage of utterances related to regulative, technical or transformative (in general) processes. We found a negative Pearson correlation between the percentage of utterances related to orientation and the scores on the definitional knowledge test ($r = -.363, p < .05$). This indicates that students with higher scores on the definitional knowledge test make fewer utterances related to orientation. A positive relation was found between the percentage of utterances related to interpretation and the definitional knowledge test scores ($r = .252, p < .05$). This indicates that students with higher scores on the definitional knowledge test made more utterances related to the interpretation of experimental results. No significant correlations were found between the "what-if" test scores and the percentage of utterances students made regarding a certain learning process.

The number of unique propositions discussed by the students is positively related to the gain score on the "what-if" test. (post minus pre-test scores) of the students ($\mathrm{r} = .301, p < .05$). Furthermore, a positive significant correlation between the gain score on the proposition test (number of correctly identified proposition post-minus pre-test) and the number of unique propositions was found ($r = .406, p < .01$).

Over all conditions, negative correlation ($r = -.488$, $p < .01$) between the percentage of agreement between the two partners working together (calculation based on the results of the proposition pre-test) and the number of unique propositions discussed during the learning session was found. Subsequently, we calculated the correlation between the percentage of agreement and the number of unique propositions discussed for each condition. For the shared proposition table condition we found a significant negative correlation ($r = .755, p < .01$) between the percentage of agreement between partners and the number of propositions discussed during the learning session. For the other conditions no significant correlations were found.

3.4 Conclusion and Discussion

The main aim of this study was to evaluate the effects of different forms of support that aimed to support the generation and discussion of propositions on students' discovery learning processes and learning outcomes. In a collaborative learning setting students might be confronted with contradicting beliefs. Confrontation with contradicting beliefs can induce a cognitive conflict and stimulate the students to rethink their own ideas (Doise et al., 1998). In order to benefit from a partners' alternative belief students have to maintain a common focus and be aware of the differences in their ideas (de Vries et al., 2002).

To investigate how we could support students during the process of proposition generation, we created three conditions. Students were working with a proposition scratchpad condition, a shared proposition table, and a control condition. The proposition scratchpad provided students with an expression builder. Students could choose variables and relations from drop down menus and construct a proposition. The shared proposition table was based on the results of a proposition pre-test. In this test students assigned a truth-value to propositions. When students entered the learning environment the assigned truth- values were combined in a so called shared proposition table that confronted students with the opinions of their partners. The shared proposition table was designed to make students aware of possible differences in opinion about the truth-value of a proposition. Overall, we found a negative correlation between the percentage of agreement within a dyad (on the proposition pre-test) and the number of unique propositions students discussed during the learning session. When we look at the conditions separately we only found a significant negative correlation (between the percentage of agreement and the number of propositions discussed by the partners) in the shared proposition table condition. This suggests that the shared proposition table encourages students to discuss initial differences.

Students working with the shared proposition table outperformed the students in the other conditions on the intuitive knowledge test and the proposition test. The logged chat protocols provide further insight in the learning processes that took place during interaction with the environment. The chat protocols showed that students in both experimental conditions made significantly more utterances related to propositions than students in the control condition. There was no significant difference between the amount of utterances made by students in both experimental conditions. However, students working with the shared proposition table discussed more different propositions than students supported by the proposition scratchpad. The number of unique propositions discussed during the learning session is positively and significantly related to the learning gain of students. This suggests a positive influence of the number of unique propositions discussed on learning outcomes.

The scratchpad as well as the shared proposition table in combination with the simulation represented the domain knowledge (or proposition) the students currently worked on, and helped students maintain a common focus and externalize task relevant knowledge (de Vries et al., 2002). However, building propositions with the proposition scratchpad remained a difficult task for students. Students working with the scratchpad spent a large deal of their time constructing propositions, which possibly explains why these students have discussed less unique propositions. Discussing the construction of a sound proposition in more detail might have resulted in knowledge and inquiry learning skills that have not been measured in this study.

Providing students with predefined propositions and visualizing the differences in opinion increased the number of propositions they discussed and resulted in better learning outcomes. Students discussed more different propositions and tested a wider range of relations present in the domain. It seems that it pays off to make students aware of their own and their partners' initial ideas and possible discrepancies between these ideas. The learning gain for the students working with the shared proposition table was significant, but not very large. We can think of a number of reasons for this. First, students worked with the simulation only for a short and limited period and focused on resolving differences in opinion. Elaborated responses and mutual effort to understand each others opinions have a positive effect on learning outcomes (Webb et al., 2002). However, students might have rushed toward agreement without fully understanding the partners' point of view, or explaining their own understanding of phenomena (Coleman, 1995). Second, students tended to treat each proposition as it was completely new and not related to propositions they already tested. The design of the environment does stimulate students to discuss individual propositions but does not stimulate them to make connections between the various propositions and integrate new knowledge in their existing knowledge base. Reflection on experiences in the simulation environment is important in order to gain structural understanding of the domain (Ruiz-Primo & Shavelson, 1996). Based on this experience a new version of the learning environment is being developed, including the shared proposition table and a tool that invites students to construct their own conceptual models in the form of knowledge maps. This tool might stimulate students to reflect upon the relationship between the propositions in the environment and help students to build a more elaborated propositional network.

4. Facilitating collaborative scientific discovery learning with shared concept maps and proposition tables

Abstract

This study investigates the effect of a collaborative concept mapping task on students' knowledge construction in a collaborative scientific discovery learning setting. Twenty-four, fourth year students from a university preparation track, participated in a discovery learning task with a computer simulation on one dimensional kinematics. The learning task involved collaborative scientific discovery and reasoning based on experiments performed with the simulation. Students were paired into dyads and randomly assigned to one out of two conditions: 1) a concept mapping condition, 2) a control group. Students in the concept mapping condition were provided with a computer supported collaborative concept mapping tool. Students in the control condition received no extra support aimed at the integration of concepts and propositions. Learning outcomes were assessed using an intuitive knowledge pre- and post-test, a proposition test and an essay question. The findings indicate that students in the concept mapping condition performed significantly better than their peers in the control group. Furthermore, students in the concept mapping condition communicated significantly more about the design and outcomes of experiments than their peers in the control condition.

4.1 Introduction

This study investigates the effects of a shared concept mapping tool on students' knowledge acquisition within a scientific discovery learning setting. Scientific discovery learning simulations can be characterized as rich and highly self regulated learning environments were students construct their knowledge based on interaction with a simulation environment. Within the learning environment students can perform experiments and observe the experimental outcomes. The newly obtained information can be used to revise or expand the prior knowledge base of the student (see also Chapter 1).

In a collaborative discovery learning setting students are not only confronted with experimental outcomes but also with the ideas of their partners. The information obtained in the collaborative discovery setting can be more or less consistent with the students' initial understanding of a phenomenon. If the new information fits within the students' current understanding of the phenomena, it is likely that the information will be integrated in the existing knowledge. However, when students encounter new information, that conflicts with their initial understanding different processes may occur. The new information might be rejected or interpreted in a way that matches the students' initial understanding (Chinn & Brewer, 1993). But conflicting information can also stimulate students to rethink and adjust their initial understanding.

Confronting students with information, data, or experiences that contradict their initial understanding of a phenomenon is often used as an instructional strategy to help students overcome their misconceptions. Confrontation might lead to a state of disequilibration, which stimulates students to reflect on their learning process and rethink their initial understandings (Piaget, 1985). In line with Piaget other researchers suggest that students are most likely to change their beliefs if they first develop dissatisfaction with their existing beliefs and identify possible alternatives (West & Pines, 1985). Consideration of alternatives, reorganization, and refinement of knowledge might eventually lead to the adoption of new and more acceptable viewpoints (Chinn & Brewer, 1993).

In a collaborative discovery learning setting students often quickly move from one experiment or conflict of opinion, to another. Often confrontation and one on one comparison of propositions is not enough to change students' knowledge structures, true conceptual change requires refinement and restructuring of the existing knowledge structure (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001; Vosniadou & Verschaffel, 2004).

In this study we introduce a concept mapping task to support students' collaborative knowledge construction process. The concept map provides students with a shared representation which they can refer to during the collaborative learning process (Roth & Roychoudhury, 1992). Furthermore, the construction of a concept map requires students to identify the key concepts, structure them logically and represent the relation between concepts.

4.2 Collaboration and confrontation

Participation in a collaborative learning task provides students with a unique opportunity for discussion, elaboration, and reflection. In a collaborative learning setting students share a common goal and share tools and activities in order to reach their goal. Sharing a goal, tools and activities creates interdependency between students and the need to communicate with each other about plans, actions, reasoning and ideas. Discussions between students are likely to reveal some of the students' initial ideas about the domain at hand as well as the inter-individual differences between collaborating students. The inter-individual differences might lead to a socio- cognitive conflict and might stimulate the students to rethink and clarify their own as well as their partners' ideas in order to resolve the differences (Doise et al., 1998). Unfortunately, not al students benefit from the discrepancies between their own and their partners beliefs. Gijlers and de Jong (2005) analyzed the students' conversation during a collaborative discovery learning session. They found a positive relation between the discrepancy in pre-test scores of the partners' and the amount of talk devoted to the design of experiments, interpretation of data and evaluation of experimental data. Nonetheless, the overall amount of discussed experiments was rather small and heterogeneity did not significantly stimulate students to generate and discuss propositions. A possible explanation for the fact that students did not thoroughly discuss the propositions and experiments is the fact that inter-individual differences and ideas about propositions are not always fully verbalized (Gijlers & de Jong, 2005). In order to benefit from cognitive conflict students have to be aware of the existing inter-individual differences.

A carefully engineered learning environment can help students to become aware of inter-individual differences and stimulate a profound discussion. De Vries, Lund and Baker (2002) report on a study with the CONNECT environment, where inter-individual differences play an important role. Their approach involved pairing students so as to maximize the difference between their individual explanations. When students entered the learning environment they were asked to judge their own and their partners' individual explanation of a sound phenomenon. Based on the nature of the individual explanatory texts, the system generated instruction aimed at the expression and discussion of ideas in the texts. De Vries et al. report that the students' interaction contained a high amount of explanation and argumentation.

A recent study by Gijlers and de Jong (submitted, see also Chapter 3) also suggests that making students aware of inter-individual differences has a positive effect on the amount of task related constructive interaction and learning outcomes. We compared students working with three different versions of the same discovery learning environment. All students individually indicated their opinion about the truth-value of specific propositions. Subsequently students were assigned to one out of three conditions: 1) a proposition scratchpad (an expression builder), 2) a shared proposition table, and 3) a control condition. The proposition scratchpad provided the students with an expression builder containing variables, relations and conditions. The shared proposition table combined students' individual opinions about the truth-value of a proposition into one shared table, displaying the inter-individual differences between the collaborating students. Students in the control condition did not receive extra support. Results indicated that students working with the shared proposition table improved significantly from pre- to post-test. Students in both the control and scratchpad condition did not improve significantly from pre- to post- test.

Close examination of students chat protocols showed that students working with the shared proposition table discussed significantly more unique propositions than their peers in the other conditions. Analysis also revealed that students tended to move from one proposition to another without interrelating concepts and phenomena and reflecting on the domain as a whole. The shared proposition scratchpad did not enhance monitoring strategies like checking for comprehension, finding the key principles by placing propositions in a larger context.

4.3 Structural knowledge

The term "structure of knowledge" refers to the organization and interrelationships of concepts in a specific domain. From research on problem solving in experts and novices it became clear that the organization of knowledge in meaningful chunks is important in the problem solving process. In contrast to novices experts organized information in large and meaningful chunks (Chi, Glaser, & Farr, 1988; Larkin, McDermott, Simon, & Simon, 1980). The relation between expertise and an efficient knowledge structures is illustrated in a study by de Jong and Ferguson-Hessler (1986). They analyzed students performance on a card sorting task and found that good problem solvers sorted the cards based on problem types, whereas poor problem solvers based their sorting on descriptive characteristics of the elements.

According to Jonassen, Beissner, and Yacci (1993) structural knowledge is essential for comprehension, recall, effective knowledge assimilation and problem solving. De Jong and Fergusson-Hessler (1996) argue that knowledge in the physic domain is characterized by strong links between elements and high levels of abstraction. This implies that successful physics students not only have access to an extensive base of knowledge about facts, concepts and, principles that are applied to a specific domain but also store this information in logical structures. The structure of knowledge is related to the dept of the knowledge. The availability of deep level knowledge (concepts and relations) facilitates generalization and abstraction that is necessary for the construction of functional hierarchical schema's and structures. The knowledge structures of novices are often built on the basis of superficial characteristics or loosely connected elements.

We can conclude that in order to become knowledgeable in a specific domain students not only have to learn concepts and formulae but also have to develop an understanding of how different concepts relate to each other and the domain as a whole. Concept mapping techniques are frequently used to promote students' structural understanding of a domain. In the following section we will explore the possibilities of concept mapping techniques in relation to collaborative discovery learning.

4.4 Concept mapping

Concept mapping enables students to interrelate ideas and concepts that they are studying and to help teachers evaluate how students organize their knowledge on a particular domain (Jonassen, 1996; Zimmaro & Cawley, 1998). Initially, Novak and Gowin (1984) defined a concept mapping as a "schematic device for representing a set of concept meanings embedded in a framework of propositions." A concept map can be seen as a visual representation of a students understanding of the domain, consisting of nodes, and labeled lines. The nodes represent the important terms and concepts in the domain. The lines denote a relationship between concepts. The labels on the lines inform us about the nature of the relation between the connected concepts.

Various studies have investigated the effect of concept mapping as an instructional activity. The outcomes of a meta-analyses report a moderate effect on achievement and a large positive effect on the students' attitude (Horton, McConny, Gallo, Woods, & Hamelin, 1993). Meaningful learning can occur when students reflect on the process of knowledge construction and intentionally attempt to integrate new knowledge with existing knowledge (Novak & Gowin, 1984). Making a concept map forces students to think about their own thought processes and knowledge structure. Furthermore, constructing a concept map helps students organize their knowledge through integration of new knowledge into an increasing complex and interrelated framework. Students are stimulated to use the newly obtained concepts and propositions in order to elaborate and refine their existing knowledge base (Zimmarro & Cawley, 1998). Fischer, Bruhn, Grasel and Mandl (2002) indicate that during a concept mapping activity students can identify missing explanations and links. Especially in a pre-structured concept mapping activity students can see which concepts and relations already have been used in the map, or which concepts they can't relate to other concepts. This will result in a more extensive network of interrelated concepts. Roth and Roychoudhury (1993) used concept mapping in a collaborative setting. The interaction protocols of their study illustrate how this collaborative concept mapping activity enhances the negotiation of meaning. While constructing the concept map students frequently discussed the nature of a relationship between two concepts. The concept mapping task was a rather open task and students were stimulated to focus on the key principles in the domain. In order to represent the most important and meaningful concepts and relations in their network students talked “abstract” science.

In order to make concept mapping a meaningful activity it is important to begin with a domain of knowledge that is familiar to the students. The structures in the concept map are somewhat dependent on the experiences students already have with the domain. Ideally, a certain text, lab activity or problem is identified and creates a context for the concept mapping activity. For example concept mapping tasks are frequently used after working on a particular task in a science lab. Fischer et al. (2002b) indicate that concept mapping tools can easily be implemented in computer supported collaborative learning environments. Simulation based discovery learning activities provide students with experiences concerning the simulated domain. In order to stimulate the integration knowledge it is important that students become aware of the connections between the newly obtained knowledge and experiences, and their existing knowledge base. This can be achieved by the reorganization, and refinement of old networks to accommodate the new information that is obtained in the learning environment. Computer supported concept mapping tools facilitate students with a map that can be easily adjusted or updated with newly obtained information.

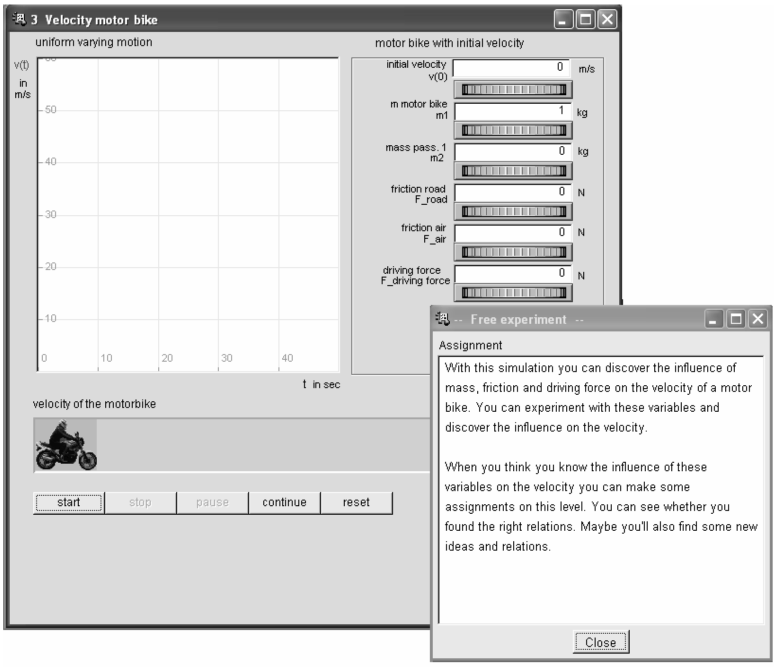
In sum, concept mapping tasks have the potential to stimulate integration of newly obtained knowledge and information. The opportunity to construct a concept map is expected to have a positive effect on students’ learning outcomes and students’ constructive dialogue about the outcomes of experiments in the discovery learning environment.

4.5 Method

In this study two conditions based on two versions of the same learning environment were realized. In the control condition students interacted with a SimQuest learning environment on one dimensional kinematics. The simulation included support in the form of model progression, assignments, and a shared proposition table. In the experimental condition students interacted with basically the same environment on one dimensional kinematics apart from an extra concept mapping tool that was added to the simulation environment. The learning environments as well as all aforementioned tools are described in the next section.

4.5.1 Learning environment

The discovery learning environment used in this study was called motion and covered the physics domain of one dimensional kinematics. The motion environment was developed with the SimQuest authoring tool. The learning environment included three levels of complexity. The first level focused on initial velocity, acceleration, time and final velocity. The second level introduced distance moved and in the third and final level the concepts mass and friction were introduced. Apart from the three progression levels, both versions of the learning environment contained support in the form of assignments and a shared proposition table.



motor bike with initial velocity

initial velocity v(0): 0 m/s
m motor bike m1: 1 kg
mass pass. 1 m2: 0 kg
friction road F_road: 0 N
friction air F_air: 0 N
driving force F_driving force: 0 N

Assignment

With this simulation you can discover the influence of mass, friction and driving force on the velocity of a motor bike. You can experiment with these variables and discover the influence on the velocity.

When you think you know the influence of these variables on the velocity you can make some assignments on this level. You can see whether you found the right relations. Maybe you'll also find some new ideas and relations.

Figure 4-1. Screenshot of the simulation with an assignment

4.5.2 Assignments

In addition, a total of 35 assignments were available to guide students in exploring the domain covered at the specific level. Learners in both conditions were free to choose any assignment. Basically, assignments presented the students with a goal and a set up of the simulation. Through these goals the assignments support the students to perform experiment and explore the environment. An example assignment is provided in Figure 4-1. Student in both condition received the same assignments.

4.5.3 Shared proposition table

The shared proposition table was based on pre-defined propositions. Each individual student completed a computerized proposition test consisting of 26 propositions. Along with each proposition three questions were asked. First, students had to specify, whether they were familiar with the proposition. Second, students had to indicate whether they thought the proposition was true, possibly true, possibly false, or false. Finally, they had to decide if they considered the proposition worthwhile to test. The answers provided to these three questions were used to construct a shared proposition table. When both students logged on to the collaborative learning environment, the system combined their individual responses, into one shared proposition table. The shared proposition table displayed the truth-value both students assigned to the propositions. Conflicting ideas between the students' answers were stressed by color. A chat tool was added to the shared proposition table to facilitate communication about the propositions (Gijlers & de Jong, submitted. See also Chapter 3, Figure 3-3).

4.5.4 The concept mapping tool

In order to stimulate students to relate concepts and propositions, available in the environment to each other we designed a concept mapping tool. After completing a progression level, dyads of students were asked to build a concept map of that level displaying all the relations between the key concepts in that particular level. The concept mapping tool provided students with a grapher for nodes and arcs. Students drew nodes, and lines and provided the accompanying concepts and relations. After completing the concept map for one level the students moved on to the next level. The constructed concept maps were saved by the learning environment and later students were able to consult a concept map they had constructed in a previous level. The environment contained three progression levels. This implies that dyads, in the concept mapping condition, built three concept maps during the experimental session.

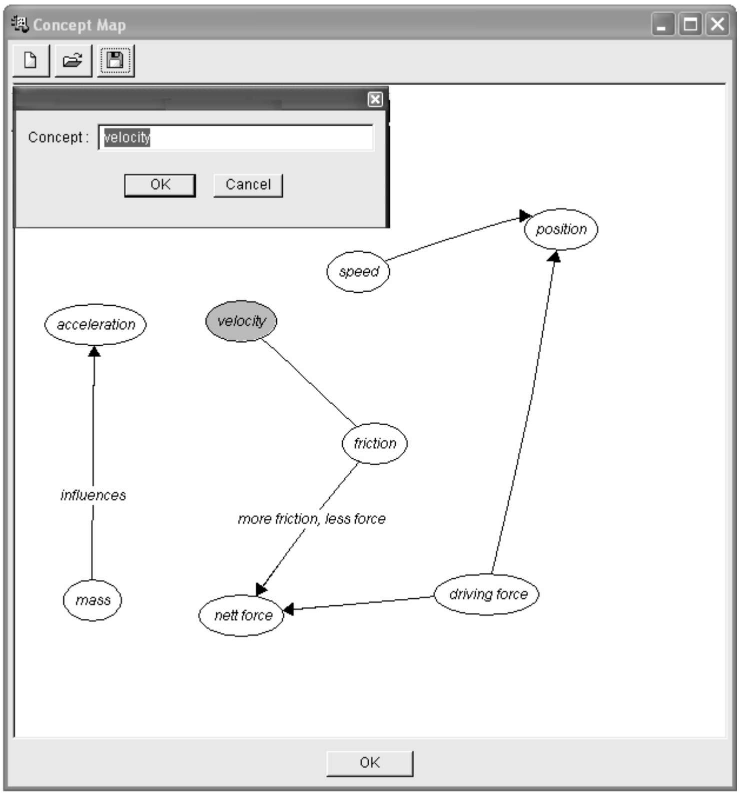


Figure 4-2. Screenshot of the concept mapping tool

4.5.5 Participants

Twenty- four students participated in the study. Their approximate age was 15. All students followed a university preparation track and completed an introduction in the domain of kinematics; this introduction covered the domain knowledge needed in the simulation environment. Students were familiar with pen and paper concept mapping tasks. The students participated in the experiment on a voluntary basis and received a small reward for their participation. All subjects had sufficient computer experience to operate the learning environment. Students were randomly assigned to dyads and subsequently the dyads were randomly assigned to one of the two conditions.

4.5.6 Instruments

Four different tests were administered, a definitional knowledge test, an intuitive knowledge test, a proposition test, and an essay question. The definitional knowledge test was administered as a pre-test only, all other tests were administered as both pre- and post-test. The definitional knowledge test focused on students' definitional knowledge about the domain and contained questions about concepts, formulae, and definitions that are relevant for the domain at hand. The test consisted of 25 (four answer alternative) multiple-choice items. Cronbachs alpha reached .62.

Discovery learning is believed to produce intuitive knowledge that cannot easily be assessed with traditional knowledge tests that focus on definitional knowledge. We used a test in the so called "what-if" format to assess intuitive knowledge. In the "what-if" test each item consisted of three parts: conditions, actions, and predictions (Swaak & de Jong, 1996). Each item started with the description of a condition (a particular state in which the simulation can be). The condition was presented by a screenshot of the simulation and some text. The action (a change of a variable) was presented to the students in text. Finally, three predicted states of the simulation were presented to the students in the form of a screenshot or text. Students were asked to decide which of the predicted states follows from the presented condition and action. The "what-if" test contained 21 items and was administered as a pre- and post-test. The coefficient alpha of the "what-if" test yielded .61 for the pre-test and, .66 for the post-test.

The proposition test focused on students' beliefs about relations within the domain. In this test students gave their view on a list of 26 propositions on a domain (see also Chapter 2, Section 2.2.4). When two students stated to work together their individual lists were combined into a shared list and they could easily inspect on what propositions they agreed and disagreed (see also this chapter 4.5.3).

The essay question was meant to assess the ability to use concepts in the domain of one dimensional kinematics interrelated. Students were asked to describe and explain the movement of a shuffle stone across a shuffle board. They were specifically asked to describe the physical factors that influenced the movement of the stone. The essay questions were scored on the number of correctly used concepts and by the completeness of the description, compared with the answer key. The score on the essay questions was determined by the number of relevant concepts the students used, and the quality of the links between concepts (propositions) as they were constructed by the students. Inter-rater agreement between two judges on ten percent of the essays reached .76 for the number of relevant concepts and .68 (Cohen's kappa) for the quality of the propositions.

4.5.7 Procedure

Students were randomly assigned to dyads. Their classroom teacher informed us about personal conflicts between students and problematic combinations of students were avoided during the experiment. Dyads of students were randomly assigned to one of the two conditions. Before the actual experiment took place students were invited to a testing and training session. In this session the prior knowledge of all students was assessed.

The students made a “what-if” test to assess their intuitive knowledge about the domain, a proposition test was used to assess students' initial beliefs about the relations in the domain and a definitional test was used to assess students' definitional domain knowledge. After completing the test students received an introduction on the learning environment. The introduction focused on the structure of the learning environment, operation of the system and the tools that were available for all students.

Table 4-1. Overview of the experimental session

Activities		**Time scale**
Training and testing	**Testing**	
	- *Essay writing*	15 minutes
	- *"what-if" test*	15 minutes
	- *Definitional knowledge test*	20 minutes
	- *Proposition test*	15 minutes
	Training	20 minutes
	- *Introduction to SimQuest*	
Experimental session	- *Introduction to concept mapping.*	15 minutes
	- *Interaction with the environment*	90 minutes
	- *Post tests*	50 minutes

Before the actual experiment, students in the experimental setting received an introduction on concept mapping, and were introduced to the concept-mapping tool in the learning environment. Students were taught to place links between concepts and label the relations represented by the links. After the instruction the actual learning session started. Students in both conditions were asked to collaboratively interact with the learning environment, perform experiments and learn more about the relations between the different concepts in the domain. Students were allowed to interact 90 minutes with the environment. After this period all students were asked to complete a "what-if" test, a proposition test, and an essay.

4.5.8 Process analysis

The chat logs were coded in a stepwise manner. First, all the dialogues were segmented into utterances. An utterance was defined as a distinct message from one student to another student or to him or herself. Second, each utterance was categorized as on- or off-task communication. Off-task communication was not further categorized. Third, on-task communication was further categorized as technical, regulative, or transformative. All utterances related to technical features of the learning environment, for instance closing and opening an assignment or window, were coded as technical. Utterances related to planning or monitoring the learning process were coded as regulative. Communication that directly yielded knowledge was coded as transformative. Fourth, all communication referred to as transformative, was further analyzed. As indicated in the introduction we distinguish the following transformative processes; orientation, proposition generation, experimentation, and interpretation. Within this particular session we coded interaction about the formulation of a link in a concept map a proposition. A proposition basically is a formulation of a relationship between various variables or concept. A concept map includes nodes (concepts), linking lines and linking phrases, which represent relations between the nodes. If students verbalize a relation between nodes connected with linking lines and a linking phrases this will be scored as a proposition. Interaction about the interpretation of linking lines and linking phrases in a concept map are coded as interpretation.

4.6 Results

In this section, we first report the results of the different knowledge test. Subsequently, we will give an overview of process measures, and, finally we report on the relation between the knowledge test and the interaction measures.

Prior to answering the research questions, it was tested whether initial differences concerning prior knowledge existed between groups. No difference between conditions were found on the results of the definitional knowledge test (F (1, 23) = .12, p>0.1) and the "what-if" pre-test (F (1, 23) = .61, p>0.1) were found. Mean scores and standard deviations of students of students' scores on the definitional knowledge test are provided in Table 4-2.

4.6.1 "What-if" test

The "what-if" knowledge test was given as a pre-test and post-test. It consisted of 21 multiple choice items with three answer alternatives. The average numbers of correctly answered items on the "what-if" pre- and post-test are given in Table 4-2. A repeated measures analysis on the "what-if" test scores showed a statistically significant learning effect for the number of correct items from pre-test to post-test (F(1,22) = 77.4, *p*<.01). And a significant interaction effect between learning effect and condition (F (1,22) = 15, *p*<.05). Students in the concept mapping condition improved significantly more from pre- to post-test.

Table 4-2. Average score on the definitional knowledge test, and the "what-if" pre- and post-test for both groups (standard deviation between brackets)

Condition	Mean scores					
	Definitional pre-test		"what-if" pre-test		"what-if"post-test	
Control	13.50	(4.08)	12.38	(2.41)	14.75	(2.45)
Concept Map	12.83	(5.32)	13.58	(2.31)	16.92	(2.94)

4.6.2 Proposition test

The proposition test was administered as a pre- and post-test. Students were confronted with propositions and were asked to indicate whether the presented proposition was true, possibly true, possibly false, or false. Based on the answers students provided we calculated the number of propositions the students correctly identified as true or false for both the pre- and post-test (see Table 4-3).

Both groups improved significantly from pre- to post-test (t (1, 23) = 5.072, *p*<.00). No significant differences between the learning gains of students in the two conditions were found.

Table 4-3. Average number of correctly identified propositions on the pre- and post-test for both groups (standard deviation between brackets)

Condition	Mean number of correctly identified propositions			
	Pre-test		Post-test	
Control condition	6.66	(3.74)	11.41	(2.11)
Concept Map	7.00	(2.73)	10.42	(2.16)

4.6.3 Essay question

The essay question was meant to assess whether students were able to use concepts in the field of kinematics interrelated when describing the movement of a certain object. In both the pre- and the post-test students were asked to describe the movement of a shuffle stone that slides across the flat surface of shuffleboard. Repeated measures analysis revealed that learning gains on the essay question were significantly higher for students in the concept mapping condition (F (1, 23) = 12.89, p<.01).

Table 4-4. Average score on the essay pre- and post-test knowledge test for both groups (standard deviation between brackets)

Condition	Mean number score on essay test			
	Pre-test		Post-test	
Control condition	7.95	(2.93)	9.29	(3.05)
Concept Map	7.02	(2.26)	10.43	(3.09)

4.7 Process measures

We logged all chat communication and actions which students made while interacting with the learning environment. This provided us with information on the actions students performed and the use of the simulation and the supportive measures. First, we will provide a quantitative overview of students chat communication. Subsequently, we will illustrate our finding by excerpts from students' chat interaction and examples of concept maps constructed during the learning session.

During the learning session students communicated with their partner through a chat tool. All utterances students made during the learning session were logged and coded using the coding scheme presented in the method section. The students made a total of 1764 utterances of which 1633 were coded as on-task communication. A detailed overview of the number of utterances students made related to the learning processes is provided in Table 4-5.

Table 4-5. Number of utterances students made in the different categories

Processes		Utterances
On/off task communication	Off-task	131
	On task	1633
	Technical	54
	Regulative	533
	Transformative	1046
Transformative processes	Orientation	241
	Proposition	263
	Experiment	347
	Interpretation	195

Table 4-6 provides an overview of the mean percentage of utterances, students in both conditions, made in the distinguished categories. An ANOVA with as dependent variables the amount of utterances made in the various learning process categories and as independent variable the condition (control or concept mapping) was performed. Students in the concept mapping condition made significantly more on-task remarks than their peers in the control condition (F (1, 22) = 4.40, $p<.05$). Furthermore, a significant difference was found between the percentages of utterances related to transformative processes. Students in the control condition made fewer transformative remarks than their peers in the concept mapping condition (F (1, 22) = 4.67, $p<.05$). With respect to the transformative processes students in the control condition made a higher percentage of remarks related to orientating processes (F (1, 22) = 5.07, $p<.05$) and significantly lower percentage of remarks related to experimentation (F (1, 22) = 4.64, $p<.05$).

Table 4-6. Overview of average percentage of remarks related to the different learning categories (standard deviation between brackets)

	Control condition	SD	Concept mapping	SD
On task	91.73	(5.89)	95.90	(3.54)
Technical	3.42	(3.21)	2.49	(3.24)
Regulative	39.78	(12.72)	30.01	(11.82)
Transformative	56.80	(11.97)	67.05	(11.25)
Orientation	25.57	(12.55)	15.71	(8.52)
Proposition	30.63	(11.51)	24.03	(12.50)
Experiment	27.41	(6.40)	38.69	(16.97)
Interpretation	16.39	(9.20)	21.57	(7.73)

4.8 Knowledge and process measures related

A correlation analysis was performed to explore possible relations between students' learning gains on the intuitive knowledge (what if) test, the proposition test and the essay question and students' communication in the discovery learning categories. No significant correlations were found between the "what-if" test scores and the percentage of utterances students made regarding a certain learning process. For the concept mapping condition a significant positive correlation between the percentage of communication coded as transformative and the learning gains on the essay question was found

($r = .625, p<.05$). For the control condition no significant correlations were found.

The following examples illustrate how students in the concept mapping condition collaboratively worked within the learning environment.

Angela and Cathy

In Table 4-7, we present an fragment of the chat communication of Angela en Cathy. Angela and Cathy are constructing a concept map and are trying to find information about the relationship between velocity and the mass of a vehicle. In turn 8 Angela suggests that they can do an experiment to find extra information. Cathy looks and the environment and decides that there is a way to find the information through an experiment (turn 9 and 10). She designs and performs an experiment. They save the graph (turn 13) and Angela purposes to increase the mass of the vehicle. She observes that this makes the vehicle slower (turn 16). Cathy decides that a map based on this information is too simple (turn 16). Cathy purposes to look for more things they can change (turn 22). Angela states that velocity is influenced by acceleration (turn 23) and Cathy agrees (turn 25). Later on Cathy and Angela discuss the relation between mass and acceleration (turn 31 to 40). They end up including mass, force and acceleration in their concept map.

During the discussion Angela en Cathy two times refer to performing an experiment. They want to conduct an experiment in order to find information about the relation between various concepts. The mapping task provides a meaningful context for searching information about the relationship between variables. The simulation offers them the opportunity to actively search for the missing information or find evidence for an idea.

Table 4-7. Episode from the chat communication of Angela and Cathy

Turn	Student	Chat message
1	Angela	Maybe you can give it a try.
2	Angela	Think about the relation between those two.
3	Cathy	O.K I will think with you
4	Angela	O.K.
5	Cathy	I think that if the mass of the vehicle is larger

6	Cathy	Well then the velocity will also be larger.
7	Angela	I don’t think so.
8	Angela	Can we make up an experiment to find out?
9	Cathy	I will look.
10	Cathy	Yeah. We can test it
11	Cathy	What are you doing?
12	Cathy	I am making the vehicle lighter
13	Angela	Lets save the graph
14	Cathy	It is saved.
15	Angela	And now enlarge the mass of the vehicle. Lets add a person
16	Angela	It is slower now.
17	Cathy	But there must be something in between. The map is too simple.
18	Cathy	We have mass and velocity.
19	Cathy	That does not explain it.
20	Angela	Well it does
21	Angela	Velocity.
22	Cathy	Is there more we can change?
23	Angela	Velocity has something to do with acceleration.
24	Cathy	Yeahh
25	Cathy	When you increase acceleration you certainly go faster
26	Angela	Whoawww
27	Cathy	Hehe
28	Angela	Well lets think
29	Angela	If acceleration increases we will go faster
30	Cathy	If mass increases we will go slower.
31	Cathy	So we have the circles with mass, acceleration and velocity.
32	Angela	Yeahh.
33	Cathy	Is acceleration influenced by mass?
34	Angela	It is the formula with force, mass and acceleration in it?
35	Cathy	What did that formula look like?
36	Angela	Can we see if we can find it out with an experiment?
37	Cathy	You do it.
38	Cathy	We must remember better.
39	Cathy	Don’t you remember?
40	Angela	Ok let’s put it this way, mass and force influence acceleration.

Martin and Peter

In Table 4-8, an excerpt from the chat communication between Martin and Peter is given. Martin and Peter work on the first level of the learning environment. In turn 1 Martin refers to a proposition from the shared proposition table. (Martin and Peter refer to the following proposition: If the acceleration of an object is larger than zero and the initial velocity doubles, the final velocity also doubles.) Peter states that he is sure that this proposition is false (turn 3). But they want to check it anyway. They design an experiment in which they double the initial velocity. They keep discussing the truth-value of the proposition (turn 9 to 11). They agree that it if there was no acceleration things would be different (turn 15 to 17). In turn 17 Martin states that the velocity versus time diagram would look different if acceleration equaled zero. He correctly states that the diagram would display a flat line. In turn 18 Peter proposes to draw this relation in the concept map. Martin and Peter use the simulation as a way to check information.

Table 4-8. Episode from the chat communication of Martin and Peter

Turn	Student	Chat message
1	Martin	Let me see this proposition
2	Peter	We can check it
3	Peter	Although I am pretty sure this is false
4	Martin	Ok, do an experiment and I will observe
5	Peter	Ok
6	Peter	And what's next?
7	Martin	We can save the graph and I will change initial speed.
8	Martin	I will double initial velocity.
9	Peter	I am pretty sure that the final velocity will not double.
10	Martin	I agree
11	Peter	You just add initial velocity up with the number
12	Peter	See the graph it does not double
13	Martin	Yeah we now just added 10 instead of 5
14	Martin	Let me see if that is true in the graph
15	Peter	Because there's acceleration
16	Martin	If there is no acceleration it's is different, and

		there is a flat line.
17	Martin	So if there is no acceleration and you double initial, final doubles
18	Peter	So, now lets draw it in the map

The chat-messages illustrate that students in the concept mapping condition discuss their experiments in the context of constructing a concept map (see the conversation between Angela and Cathy in Table 4-7). They use the simulation to find extra information for their concept map or check ideas about propositions before actually including them in their concept map. Students in the control condition mainly used the concept map to find information about the truth-value of propositions that were displayed in the shared proposition table. Students tended to focus on the propositions they disagreed about and conducted experiments aimed to test these propositions without discussing the design and outcomes of these experiments in detail.

4.9 Discussion

The first main finding of this study is that, as a whole, students in both conditions improved on the intuitive knowledge test and the essay question. Student in the concept mapping condition scored significantly better, at these knowledge measures, than their peers in the control condition. This is in-line with the idea that concept mapping does have a positive effect on students knowledge about relations in the simulated domain (Jonassen et al., 1993; Jonassen & Wang, 1993). On the basis of these results we can conclude, that a concept mapping task as well as the shared proposition table had a positive effect on students intuitive knowledge. The concept mapping task also enhanced learning about structures and interrelations in the domain (as assessed by the essay question).

From the analyses of the chat-messages it became apparent that students in the concept mapping condition spent a higher percentage of utterances discussing experiments, than their peers working with the shared proposition table. Analyses of the log files revealed that students in the control condition actually conducted more experiments in the learning environment, which indicates that students in the concept mapping condition performed fewer experiments and discussed these experiments in detail.

In our data we found a relation between students' chat messages in the different learning categories and the results on the essay question. For students in the concept mapping condition there was a positive relation between the percentage of utterances made regarding transformative processes and their learning gains on the essay question. Discussing experiments and experimental outcomes in more detail, interrelating the newly acquired knowledge and linking it to prior knowledge is important in the process of knowledge construction (Novak & Gowin, 1984).

Another important observation from this study is that students did not use the concept mapping tool as a support tool when working with the simulation, but used the simulation as a source of information during the concept mapping task. Within the limited time frame of the experiment students tended to focus on the concept mapping task. Students in the concept mapping condition hardly used the assignments and the shared proposition table that were available in the learning environment. The results of the qualitative analyses reveal that students construct concept maps based on prior knowledge, interaction with their partner, and their interaction with the simulation environment. The excerpts presented in Table 4-8, for example illustrates that Martin and Peter use the simulation to check their initial idea about the relation between initial velocity, final velocity, and acceleration.

We can conclude that, the introduction of a concept mapping task created a natural and stimulating setting for performing and discussing experiments and using the simulation. The concept mapping task stimulated the students to perform experiments, discuss experimental outcomes and use different concepts interrelated. We realize that students in the concept mapping condition heavily focused on the concept mapping task and less frequently used the other supportive measures in the learning environment. This may change when more time is available to explore the learning environment.

5. Discussion and outlook

Abstract

In this chapter, the overall results of the three studies from this thesis (Chapters 2, 3, and 4) are discussed. First, the collaborative discovery learning process and the influence of prior knowledge on this process is examined. This is followed, by a discussion of the different tools to support the students' collaborative knowledge acquisition process. A comparison between the tools used in the second and third study suggests that different tools stimulate different knowledge construction processes. Finally, some implications for educational practice and future research will be discussed.

5.1 Introduction

Scientific discovery learning is a complex process that consists of a number of specific learning processes. Research indicates that students may experience serious problems with the learning processes that comprise scientific discovery learning leading to the conclusion that unsupported discovery learning is not very effective (Mayer, 2004). In a computer based discovery learning environment support can be included to assist students during discovery learning. This results in what has been called supported scientific discovery learning or inquiry learning (de Jong, in press). This dissertation started from the idea that introducing peer collaboration might be a natural way to support students' in their discovery learning process. In a collaborative learning setting students have to make their plans, actions and ideas explicit, this explication is expected to have a positive effect on a number of discovery learning processes. The introduction of collaboration is not likely to address all the problems students experience in a discovery learning setting. New problems related to the regulation of collaboration and communication processes might occur (Kanselaar & Erkens, 1996).

The goal of this thesis was to investigate whether it was possible to support the collaborative scientific discovery learning process through tools within a learning environment. For the design of supportive tools an understanding of the learning processes that occur in such a setting was necessary. The goal that was guiding the research presented in this thesis consisted of two sub questions. The first question focused on the collaborative discovery learning process and investigated the processes that comprise the collaborative discovery learning process and the influence of prior knowledge on these processes. This question was addressed in the first study (Chapter 2). The second question addressed the design and evaluation of tools supporting the collaborative scientific discovery learning process and was addressed in the second and third study (Chapters 3 and 4).

5.1.1 Study 1: Exploring collaborative discovery learning

The first study was an exploratory study investigating the knowledge acquisition process in a collaborative scientific discovery learning setting. Research indicated that learning in a collaborative setting is influenced by the type of learning task, group composition, the complementarities of the participants' expertise, and the available resources and tools (Kanselaar et al., 2003). In the studies presented in this thesis students participated in a kinematics learning task. The goal of the instructional activity was to improve students understanding of one dimensional kinematics. The learning activity focused on collaborative discovery learning and reasoning in a computer based simulation environment. Within the learning environment students could change the value of an input variable(s) of a simulation and observe the behavior of outcome variables. The available simulations, graphs and animations provided opportunities for collaborative knowledge construction and reasoning (Roth, 1995). Group composition is another important factor in the collaborative knowledge acquisition process. In this thesis we mainly focus on the complemantarity of students' prior knowledge.

In a collaborative learning setting prior knowledge and ideas of the individual students are generally seen as an important factor in the collaborative learning process. Okada and Simon (1997) stated that in collaborative discovery learning the collaborating students influence each other's learning process. Students are confronted with and react upon the actions and ideas of their partner and progress through a process of building on each others knowledge as well as arguing and criticizing each others ideas. In addition, when students are lacking the knowledge needed to perform a certain action their partner might be able to assist them. However, this is only possible when the prior knowledge base of the partner includes the knowledge needed to assist their peer(s). Also, students might find that their partner's ideas and plans are not in line with their own reasoning or planning. In this case students have to discuss their different viewpoints in order to continue the collaboration with a plan or idea that is acceptable for all participants.

In Chapter 1 we introduced the extended SDDS model for two students. This model indicated that not only the prior knowledge of the individual student, but also the knowledge of the partner has the potential to influence the discovery learning process. Based on the extended SDDS model for two students we asserted that certain combinations of prior knowledge offered more possibilities for fruitful collaboration than others. In our first, exploratory, study, students worked in dyads on a computer supported discovery learning task in one dimensional kinematics. The dyads shared a computer and communicated face-to-face. Before students interacted with the learning environment their definitional domain knowledge, discovery learning skills, and generic knowledge (mathematical and graph related knowledge) were assessed. Furthermore, each student individually completed a questionnaire about the truth-value and testability of a series of domain related propositions. The communication between the students was recorded and provided rich information about students' collaborative scientific discovery learning process. The discovery learning processes distinguished by de Jong and Njoo (1992), orientation, proposition generation, experimentation, and interpretation formed the bases of a coding scheme for the transcribed interaction protocols.

Correlational analyses revealed that group composition in terms of prior knowledge affected the collaborative discovery learning process. There was a positive relation between the heterogeneity of dyads and the amount of utterances made related to stating propositions and explaining experiments. The conversation of the more homogenous low and average achieving dyads focused on orientation processes.

These results suggested that homogeneous dyads who share a limited amount of prior knowledge found it difficult to identify potential interesting variables in the learning domain. This is in line with the idea that heterogeneous group composition leads to higher learning gains (Webb et al., 2002). Low achieving students can learn from the help provided by the high achieving student. High achievers progress through the cognitive restructuring involved in peer tutoring (Webb & Palincsar, 1996).

Based on students' individual judgments concerning the truth-value and testability of the propositions, detailed knowledge configurations for each dyad could be created. The knowledge configurations reflected the complimentarities of students' domain related ideas and beliefs. The SDDS knowledge configurations revealed that when two students have different opinions or prior knowledge this is likely to influence their discovery learning processes as well as their communicational interactions. When students share a large proportion of correct knowledge (reflected by the overlap between the domain spaces of both students and the target conceptual model), there is less need for discussion and explanation. Students can start exploring the domain on the bases of their shared prior knowledge. When there is a large overlap between the target conceptual model and the domain space of one student and a small overlap between the target conceptual model and the domain space of the second student, the first student can assist and guide the second student during the learning process.

The interaction protocols of the exploratory study revealed only a few cases where students verbalized the relation between variables in the domain. Generating a testable proposition is one of the central processes in discovery learning and serves as a basis for further experimentation. Two possible explanations for the relatively low number of propositions stated during the learning session were identified. The first explanation is that the majority of students find it hard to state a syntactically correct proposition (de Jong & van Joolingen, 1998). The second explanation is that students form ideas about the relationships between the variables in the domain but do not verbalize these ideas. If the propositions formed by students stay implicit, students cannot benefit from their partner's propositions.

In the context of this thesis three tools were designed to support the collaborative discovery learning process, and more specifically the processes related to the generation of propositions. In the next section we will discuss the design and evaluation of these tools.

5.2 Supporting the collaborative discovery learning process

In the second and third study, three tools to support the collaborative discovery learning process were introduced and evaluated. In the second study we introduced a shared hypothesis scratchpad and a shared proposition table. In the third study we introduced a shared concept mapping tool. In this section we will provide a short description of the tools and summarize the main findings.

5.2.1 Study 2: Sharing and confronting propositions

From the first exploratory study it became clear that differences in prior knowledge and opinion influenced the collaborative learning process. In general students made only a limited amount of statements about the relations between variables in the domain. Therefore, students often were not aware of the fact that their ideas conflicted with their partner's ideas. In the second study we compared two tools that addressed this problem. The shared proposition scratchpad was designed to facilitate the collaborative construction of propositions whereas the shared proposition table confronted students with predefined and syntactically correct propositions (but not necessarily correct from a domain point of view) and externalized inter-individual differences in the opinion about these propositions.

In an experimental study we compared three versions of a one dimensional kinematics learning environment. The first (control) version contained no extra support related to proposition generation or testing. In the second version of the environment students were supported with the proposition scratchpad, and in the third version of the environment students worked with the shared proposition table. Individual students worked on separate computers, with a shared desktop and communicated with their partner through a chat channel.

The study revealed that students working with the shared proposition table outperformed students working with the shared proposition scratchpad and students in the control group on an intuitive domain knowledge test (“what-if” test). Students working with the shared proposition scratchpad still experienced problems formulating a testable proposition. These students tended to spend a large part of the session constructing only a few propositions. This left them relatively little time to explore the domain and perform experiments. Students working with the shared proposition table did not experience this disadvantage. They had access to a list of predefined testable propositions. The proposition table externalized students’ believes about the truth-value of the presented propositions. This implied that students could benefit from initial differences in opinion. The combination of pre-defined propositions and externalization of ideas allowed students to explore and discuss a large amount of domain related propositions.

Although, the shared proposition table resulted in better learning outcomes than the other conditions, we also observed some drawbacks of the tool that may relate to students’ task perception. Students tended to focus on resolving conflicting truth-values, instead of gaining understanding of the structure of the simulated domain. This is reflected in our observation that students moved from one proposition to another without relating their ideas and experimental outcomes to prior knowledge, experiments, and experiences. Furthermore, students tended to focus on situations where their opinions about the truth-value of a proposition conflicted. This implied that students hardly discussed or tested propositions, where they both assigned the same *incorrect* truth-value.

5.2.2 Study 3: Co- constructing concept maps

In the third study we attempted to address the drawbacks of the shared proposition table by adding a shared concept mapping tool. The concept mapping tool allowed students to build collaborative representations of their ideas about the domain. The constructed concept map could be edited during the course of the learning session. This implied that information obtained through interactions with the simulation could easily be implemented in the concept map.

The nature of the concept mapping task invited students to discuss the structure of the domain knowledge with their peers (van Boxtel et al., 2000). Furthermore, the concept mapping task provided students with a shared representation which may help students maintain a common focus (Roth & Roychoudhury, 1992). The effects of the concept mapping tool were investigated in an experimental study. In this study two versions of the same learning environment were compared. Students in the control condition worked with a version of the learning environment that included model progression, assignments, and a shared proposition table. Students in the experimental condition received the same tools and were additionally provided with the concept mapping tool. Students in both conditions significantly improved from pre- to post-test on an intuitive knowledge test. Students in the concept mapping condition improved significantly more from pre- to post-test than their peers in the control condition. Furthermore, the learning gains on the essay question were significantly higher for students in the concept mapping condition.

The evidence suggests that these learning gains may be explained by the fact that students provided with a shared concept mapping tool focused on the construction of a representation of the simulated domain as hypothesized. However, the log files also suggest that students in the concept mapping condition paid only limited attention to the information in the shared proposition list. Students provided with the shared proposition table, focused on conflicting opinions, and performed experiments that were related to their conflicting opinions.

5.3 Different tools, different processes

The tools used in study 2 en 3 all focused on the process of generating and discussing propositions but differed on the dimensions: directive vs. non directive and restricting vs. stimulating (Njoo & de Jong, 1993). Directive support tools stimulate students to perform certain actions, whereas non directive supports don't appear to. An assignment that requires students to investigate a particular relation between variables is a form of directive support. Providing students with a library with background information about the available variables is a less directive form of support. Restrictive support constrains students' freedom in the environment, whereas 'stimulating' types of support allow more student freedom. Providing students with a list of propositions they are allowed to test is more restrictive than allowing them to construct their own propositions with an expression builder. Allowing students to state their own ideas about the domain in natural language is the least restrictive form. This section seeks to explain how different processes were supported by the tools by examining their dimensional characteristics and their elicitation of student prior knowledge.

The shared proposition scratchpad, the shared proposition table (second study) and the shared concept mapping tool (third study) focused on the process of generating, testing, and discussing propositions. The shared proposition table was a relatively directive and restrictive tool in that it confronted students with a list of *predefined* propositions. Students were expected to select, discuss, and investigate propositions from the presented list. Along with each proposition the table directed students to an experimental set-up that was suited for testing specific propositions. The shared proposition scratchpad was less directive and restrictive: the composed propositions were generated from the students' knowledge. Students working with the shared proposition scratchpad were free to construct, discuss, and investigate any proposition they could state within the template of the proposition table. Therefore, the format of the template assured that the statements constructed by the students resulted in syntactically correct propositions. Students had to design their own experimental set-up and were not directed towards a specific state of the simulation or assignment. The shared concept mapping task provided student with a graphing tool that allowed them to construct a concept map displaying the relations between key concepts in the domain. This tool was the least directive and regulative. Students were free to use their own choices with regard to concepts and relations investigation. The format of the concept mapping tool was less directive than the format of the shared proposition scratchpad. The shared proposition scratchpad required students to construct a proposition in a fixed format, describing a relation between variables that were available in the drop-down menu's provided by the tool. The shared concept mapping tools allowed students to use natural language describing the relations between different variables.

Furthermore, the tools differ with respect to their focus on inter-individual differences. The shared proposition scratchpad and the shared concept mapping tool stimulate students to collaboratively construct a proposition or concept map. During the collaborative construction of a proposition of concept map conflicts may become evident, and might even provoke conceptual change, but this is not the primary goal of the shared proposition scratchpad and the shared concept mapping task. The shared proposition list focuses more on the existing differences in prior knowledge and opinions about propositions and relies on the creation of a socio-cognitive conflict.

The following two excerpts illustrate how students worked with respectively the shared proposition table and the shared concept mapping tool. In the first example (see Table 5-1) Robin and Mart discuss a proposition on the relationships between acceleration, mass and force. A disagreement externalized through the shared proposition table and triggered a discussion between Robin and Mart. Robin focuses the attention to a case of disagreement as displayed in the shared proposition table (turn 1). Robin and Mart continue discussing the truth-value of the presented proposition. Mart refers to his own experiences by introducing the Ferrari (turn 7). Robin interrupts his suggestion and tries to provide a more scientific explanation, including mass and acceleration (turn 8).

Table 5-1. Episode from the chat communication of Robin and Mart

Turn	Student	Chat messages
1	Robin	Here's a case of disagreement
2	Mart	I don't think this is true.
3	Robin	Why not?
4	Mart	It is different for each vehicle.
5	Robin	Huh
6	Robin	That actually what is meant here
7	Mart	But a Ferrari is faster than a …
8	Robin	It is different for different vehicles because, vehicles differ on mass, acceleration and so on.

In the next excerpt (see Table 5-1) Marcy and Paul are working on a concept map representing the relationships between acceleration, mass and force. The excerpt shows that in the discussion is initiated by the mutual construction of the concept map. Marcy purposes that mass should be included in the map. Paul states that mass is linked to acceleration (turn 3). Marcy asks if Paul knows of any other concepts that should be included. He states that net force should be included. Marcy and Paul are not clear about the exact relation between the variables (turn 7 and 8). Marcy suggests they should try to find more information.

Table 5-2. Episode from the chat communication of Marcy and Paul

Turn	Student	Chat messages
1	Marcy	We need to include something about the mass in the map
2	Marcy	We did an experiment on that.
3	Paul	Mass and acceleration are linked
4	Marcy	Do you know another concept to include
5	Paul	Uhhh hum
6	Paul	Ok net force should also be linked to it.
7	Marcy	What should be on the linking line
8	Paul	I don't know
9	Marcy	We should try to find it somewhere

From the presented excerpts it becomes clear that the discussion between Mart and Robin is triggered by the difference in opinion that is visualized in the shared proposition table. Mart and Robin continue their discussion trying to reach agreement about this predefined proposition. Marcy and Paul's discussion focuses on the construction of a collaborative concept map. Their discussion and discovery activities are not directed by a list of predefined propositions, but are elicited through the notion that their concept map is not complete.

The results of the second and the third study as well as the examples presented in Table 5-1 and Table 5-2 sugget that the different tools trigger different processes, due to differences in levels of directiveness and restrictiveness. Additional sequential sequence analyses might provide insight in the different stages in the collaborative learning process. The sequential analyses can provide further insight in the way interaction concerning coordination and regulation of the collaboration and interaction related to transformative processes, as defined in this thesis, occur in the interaction

5.4 Stating ideas about the domain.

The shared proposition scratchpad as well as the shared concept mapping tool allowed students to state their ideas about the domain. The results of the second study (Chapter 3) revealed that students working with the shared proposition scratchpad did not improve significantly from pre- to posttest. Even with the support of the proposition scratchpad stating a proposition remained a difficult and time consuming process. Students were only able to state and test a limited number of propositions and therefore explored the domain only partially. Inspection of the interaction protocols suggests that some students found it hard to operate the shared proposition scratchpad. Participating students were familiar with making statements about relations between variables, but the structure of the "sentence" created with the proposition scratchpad was somewhat formal (scientific) and unfamiliar. The shared concept mapping tool used in the third study (Chapter 4) provided students with a grapher to state their ideas about relations in the domain. The interaction protocols and log files suggest that students find the shared concept mapping tool relatively easy to use. In contrast to students working with the shared proposition scratchpad, students explored a large part of the domain, as is reflected in the constructed concept maps. The concept mapping tool allowed the students to represent their ideas about the domain in a freer format. Students could use the nodes and linking lines to express all their ideas about the domain. Not all concepts and propositions (concepts connected with linking lines) that students initially used in their concept maps were correct or relevant for the domain. But the constructed representations facilitated a discussion about the structure of the simulated domain.

The logfiles and interaction protocols suggested that students working with the shared concept mapping task perceived it as their "major learning task" or overarching goal. They used the simulation as a resource to find extra information and evidence. During the construction of the collaborative concept map students noticed that they missed certain information about the domain and this guided their discovery behavior with the simulation. It seems that the concept mapping task created a meaningful context for the discussion of ideas and students' discovery learning behavior.

In Study 3, students had access to the shared proposition table as well as the shared concept mapping tool. The log files suggest that the experiments conducted by students in the concept mapping condition were to a large extent triggered by the concept mapping task and to a lesser degree by conflicting ideas (as presented in the shared proposition table). However, the fact that students had access to the shared proposition table may have influenced the learning process and outcomes. The fact that students did not optimally use the shared proposition table, by confronting and discussing propositions, does not mean that students did not use the information as it was presented in the predefined propositions. The information about concepts and relations as presented in table might have influenced the construction of concept maps and students learning outcomes.

5.5 Implications

Looking back at the three studies described in this thesis, the general conclusion that can be drawn is that peer collaboration has the potential to guide students during their discovery learning process. However, we found that in order for students to benefit from collaboration it is important that students externalize their thoughts and ideas with their peers. It was expected that collaboration would stimulate students to share their plans and ideas with their partner. The results of our first study suggested that students often did not state propositions about the relation between variables in the domain, but that confronting prior knowledge and ideas might have a positive effect on the collaborative scientific discovery learning process. In the second and third study both the shared proposition table and the shared concept mapping tool helped students to externalize their ideas about relations in the domain and triggered meaningful interaction about the domain.

In this final section we will address some issues related to the educational implications of the presented research, and future research on collaborative discovery learning

5.5.1 Implications for education

From the first study presented in this thesis it became clear that group composition, based on students' prior knowledge, is an important factor influencing the collaborative discovery learning process. Students with complementary skills and prior knowledge, but not too far different, assisted each other during the learning process. Responsiveness to help requests and active help-seeking behavior were also identified as an important factor if we want students to benefit from their partners' knowledge base (Saleh, Lazonder, & de Jong, 2005; Webb et al., 2002).

The results of the second and third study indicated that the shared proposition table as well as the shared concept mapping tool effectively assisted students during their collaborative discovery learning process. Both tools helped students maintain a common focus by providing them with pre-defined propositions or a shared representation of the domain and helped students respectively identify conflicting opinions and missing information.

The strategies presented in the shared proposition table as well as the concept mapping task offer opportunities for meaningful classroom activities. The different characteristics of the tools make them more or less suited for the acquisition of certain learning goals.

The shared proposition table was a rather directive and restrictive tool (see Section 5.3). The predefined propositions guided students along important parts of the simulated domain. The shared proposition table was suited for discussing a relative large proportion of the domain. The fact that students approached each proposition as if it was new and unrelated to previously discussed proposition suggest that the shared proposition table is less suited for acquiring structural knowledge. This is inline with the statement that more directive and restrictive tools are less suited for the construction of deep knowledge and mindful abstraction (Veermans, de Jong, & van Joolingen, 2000).

The shared concept mapping activity triggered students to perform goal driven experiments, in order to find extra information needed to construct the concept map. The fact that students discovery learning processes started from a concept mapping activity, makes it more likely that their learning is related to the acquisition of structural domain knowledge. The freer format of the concept mapping activity makes it more difficult for teacher to guide students along important aspects of the domain and control the activities of learners in the domain.

An implication for education that can be drawn from these findings is that in a collaborative discovery learning setting, special attention has to be given to the composition of groups and effective explanation and help seeking behavior. Providing students with opportunities to compare, evaluate, and discuss opinions and responses seems to trigger domain related discussion.

5.5.2 Directions for future research

The students that participated in this study were contacted through their science teachers. In agreement with the school boards and the science teachers it was decided that, varying across schools, approximately four periods (of 50 minutes) were available for participation in the experiment. This implied that only limited time was available for testing and interaction with the environment. Time constraints might have had a negative effect on the way students worked with the proposition scratchpad. During the experiments presented in this thesis, only a limited amount of time was available for interaction with the learning environment, and there was only little time to get acquainted to the support tools. It might be interesting to investigate the effect of the proposition scratchpad over a longer period of time, providing students with an opportunity to practice the operation of the tool.

Furthermore, it seems that the proposition scratchpad does not support students in acquiring domain related knowledge in a relative short learning session. The log files and interaction protocols suggest that students working with the scratchpad discussed the structure of different propositions in detail and thoroughly considered various issues related to the design of an experiment suited to test their proposition. Therefore, it might be interesting to investigate the effect of the proposition scratchpad on students' discovery learning skills in general and more specifically the generation of propositions.

Although it paid off to make students aware of confronting ideas, and provide them with the possibility to discuss and test these ideas, students provided with multiple forms of support may have attended only to one. The results of the third study suggest that though students supported by a shared proposition table and a shared concept mapping tool out-performed their peers who only received the shared proposition table, they did not optimally use the shared proposition table. Operating both tools during the learning process might be difficult for students. A more detailed analysis might provide insight in the effects of the shared proposition scratchpad on students' concept mapping activities. It might be interesting to combine the basic idea of the shared proposition table (externalization of individual opinions) and the concept mapping tool into a tool that compares the concept maps constructed by individual students.

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Samenvatting
Dutch Summary

Recentelijk wordt leren meer een meer gezien als een kennis construerend proces, waarin de leerling een actieve rol speelt. Vormen van onderzoekend (wetenschappelijk ontdekkend leren) sluiten aan bij deze ontwikkelingen. In dit proefschrift staat onderzoekend leren met een computersimulatie omgeving centraal. De actieve en kennisconstruerende activiteiten van de leerling in onderzoekend leeromgevingen wordt verwacht te leiden tot diepe en intuïtieve kennis. Onderzoek naar onderzoekend leren met computersimulaties heeft echter niet geresulteerd in een eenduidig positief beeld van de leeruitkomsten. Een van de redenen hiervoor is dat onderzoekend leren een complex proces is. Dit uit zich onder andere in problemen die leerlingen ondervinden bij het opstellen van hypothesen en het ontwerpen van goede experimenten om deze hypothesen te testen. Om leerlingen te ondersteunen tijdens het onderzoekend leren in simulatie omgevingen zijn verschillende vormen van ondersteuning ontwikkeld (de Jong & van Joolingen, 1998).

Naast individuele ondersteuning kan het proces van onderzoekend leren ook worden ondersteund door het introduceren van samenwerking. Samenwerkend leren stimuleert leerlingen om regulatieve en kennisconstruerende processen expliciet te maken. Voor een efficiënte samenwerking is het immers noodzakelijk dat leerlingen communiceren over de planning. Daarnaast moeten de acties van de lerende in de leeromgeving op een voor de medeleerling begrijpelijke manier worden toegelicht en uitgevoerd. Het verbaliseren van kennis en ideeën tijdens deze communicatie heeft naar verwachting een positief effect op het onderzoekend leerproces. Het is niet te verwachten dat de introductie van samenwerking alle problemen oplost. Het is zelfs mogelijk dat het combineren van onderzoekend en samenwerkend leren tot nieuwe problemen zal leiden, gerelateerd aan de dialoog tussen de leerlingen en de gezamenlijke acties in de leeromgeving (Kanselaar & Erkens, 1996).

Het doel van het beschreven onderzoek was het ontwikkelen van ondersteuning voor het samenwerkend onderzoekend leerproces. Om adequate vormen van ondersteuning te kunnen ontwikkelen was het van belang inzicht te krijgen in de karakteristieke mogelijkheden en problemen die optreden tijdens het samenwerkend onderzoekend leren. Het beschreven onderzoek heeft zich in eerste instantie dan ook gericht op het beschrijven van het samenwerkend ontdekkend leerproces en de rol van voorkennis tijdens dit proces (Hoofdstuk 1). In tweede instantie zijn, op basis van de uitkomsten van het eerste onderzoek, vormen van ondersteuning ontwikkeld (Hoofdstukken 2 en 3).

Het eerste onderzoek:
Voorkennis en samenwerkend ontdekkend samenwerkend leren

Het eerste onderzoek betrof een verkenning van het samenwerkend onderzoekend leerproces. Onderzoek geeft aan dat voorkennis van leerlingen een belangrijke rol speelt tijdens het samenwerkend leerproces (Kanselaar & Erkens, 1996; Okada & Simon, 1997). Tijdens het samenwerken worden leerlingen geconfronteerd met de kennis en ideeën van hun partner. Gedurende de dialoog kunnen leerlingen kunnen elkaars kennis aanvullen, hiaten in kennis constateren of kritiek uiten op elkaar.

De resultaten van het eerste onderzoek laten zien dat de wijze waarop leerlingen elkaar kunnen assisteren tijdens het samenwerken voor een deel afhankelijk is van de manier waarop hun voorkennis op elkaar aansluit. Tijdens het onderzoek hebben leerlingen in tweetallen gewerkt met een onderzoekend leeromgeving over het kennisdomein eendimensionale beweging. De leerlingen deelden een computer en communiceerden mondeling. De voorkennis van de leerlingen werd in kaart gebracht met behulp van een domein kennis toets, een generieke kennistoets en een propositie toets. De domein kennistoets richtte zich op kennis van concepten en definities met betrekking tot het gesimuleerde domein (één dimensionale kinematica). De generieke kennistoets richtte zich op ontdekkingsvaardigheden en algemene wiskundige vaardigheden zoals het aflezen van grafieken en lezen van tabellen. De propositie toets bestond uit een lijst van proposities, waarvan leerlingen telkens het waarheidsgehalte moesten aangeven.

Uit analyse van de interactie protocollen kwam naar voren dat de leerlingen over het algemeen weinig opmerkingen maakten die betrekking hadden op het formuleren van proposities. Er werd een samenhang gevonden tussen de samenstellingen van tweetallen (op basis van voorkennis) en de inhoud van de dialoog. De dialoog van homogene, laag en gemiddeld presenterende, tweetallen richtte zich op oriënterende processen zoals het identificeren van belangrijke concepten en het globaal verkennen van de leeromgeving. De inhoud van de dialoog van de meer heterogene tweetallen was veel meer gericht op het formuleren en testen van proposities. Deze resultaten suggereren dat tweetallen waarin beide leerlingen de beschikking hebben over beperkte voorkennis het moeilijk vinden om potentieel interessante variabelen en relaties te ontdekken en om te zetten in een propositie en experiment.

De rol van voorkennis werd ook geïllustreerd door het aangepaste SDDS (Scientific Discovery as Dual Search) model voor twee leerlingen. Het in Hoofdstuk 2 beschreven model laat zien hoe de voorkennis en meningen van twee leerlingen op elkaar aansluiten en hoe dit het leerproces en de dialoog kan beïnvloeden. Als twee leerlingen een relatief grote hoeveelheid correcte kennis delen is de behoefte aan uitleg, elaboratie en discussie kleiner dan wanneer een van de leerlingen over meer correcte kennis beschikt dan zijn partner. In dit laatste geval is kan de leerling met de meeste voorkennis zijn partner assisteren tijdens het leerproces.

Het tweede onderzoek:
Ondersteuning van het samenwerkend onderzoekend leerproces

De interactie protocollen uit de eerste studie lieten zien dat leerlingen zelden een uitspraak deden over de relatie tussen twee variabelen. Het genereren van een propositie is echter een belangrijk onderdeel van het onderzoekend leerproces en dient als basis voor het uitvoeren van experimenten. Een mogelijke verklaring hiervoor is dat leerlingen wel ideeën vormen over de relatie tussen variabelen maar deze niet verbaliseren. Op deze manier kunnen leerlingen niet optimaal profiteren van elkaars voorkennis en ideeën.

In het tweede onderzoek zijn twee vormen van ondersteuning vergeleken die zich richtten op het genereren en bespreken van proposities. Hiertoe zijn drie versies van dezelfde onderzoekend leeromgeving ontwikkeld. De ondersteuning die in deze omgevingen werd aangeboden verschilde. In de eerste versie van de leeromgeving hadden leerlingen de beschikking over een gedeeld propositie kladblok, in de tweede versie hadden leerlingen de beschikking over een gedeelde propositie tabel. De derde bevatte geen ondersteuning aan gericht op het opstellen en testen van proposities.

Het kladblok bood de leerlingen de mogelijkheid gezamenlijk een propositie op te stellen op basis van een reeks in het kladblok aanwezige elementen (variabelen, relaties, en restricties). Het kladblok werd verondersteld de leerlingen te ondersteunen bij het opstellen van een syntactisch correcte propositie. De tweede vorm van ondersteuning betrof een gedeelde propositie tabel. Op basis van de resultaten van de (individuele) propositie toets werd een tabel met meningen van de samenwerkende leerlingen over het waarheidsgehalte van een lijst proposities samengesteld. Verschillen in mening werden in de tabel zichtbaar gemaakt door gebruik van kleur. De tabel gaf leerlingen de mogelijkheid de propositie te testen door ze toegang te geven tot een relevant experiment. De tabel werd verwacht de discussie over proposities te stimuleren. Het ondersteunen van het opstellen van proposities en het stimuleren van de dialoog betreffende proposities werd verwacht een positief effect te hebben op het leer resultaat. De tweetallen (ongeacht conditie) werkten aan gescheiden computers met een gedeeld beeldscherm en communiceerden via een chattool.

De leeruitkomsten werden gemeten met behulp van een intuïtieve kennis toets en een propositie toets (voor- en natoets). Het bleek dat leerlingen die werden ondersteund door middel van een gedeelde propositie tabel vooruit gingen op de intuïtieve kennis toets. Tevens stelden leerlingen die werkten met de gedeelde propositie tabel hun mening betreffende het waarheidsgehalte van de proposities in die propositie toets vaker in de juiste richting bij. De leerlingen die werkten met het gedeelde propositie kladblok of de omgeving zonder extra ondersteuning boekten geen significante leerwinst. Nadere analyse van de interactie protocollen liet zien dat leerlingen die met de gedeelde propositie tabel hadden gewerkt meer verschillende proposities hadden besproken dan de leerlingen in de overige condities. Inspectie van de protocollen liet tevens zien dat leerlingen slechts sporadisch opmerkingen maakten over de relatie tussen verschillende proposities en het domein als geheel. Leerlingen behandelden iedere propositie alsof het een compleet nieuwe situatie betrof. De gedeelde propositie tabel stimuleerde wel de discussie over verschillende proposities maar stimuleerde leerlingen niet de besproken proposities in een groter geheel te plaatsen.

Het derde onderzoek: Concept mapping

Hoewel het gebruik van de gedeelde propositie tabel resulteerde in leerwinst en de dialoog tussen leerlingen stimuleerde bleek de tabel minder geschikt voor de acquisitie van structurele domein kennis. Voor het bereiken van een diep begrip van een kennisdomein is het echter van belang dat leerlingen niet alleen kennis hebben van losse concepten en proposities maar ook begrijpen hoe de verschillende concepten en proposities zich tot elkaar en het domein als geheel verhouden (Jonassen et al., 1993). In het derde en laatste onderzoek is gebruik gemaakt van een concept mapping taak om de constructie van structurele kennis te bevorderen. De concept mapping taak werd geïntegreerd in de onderzoekend leeromgeving. Leerlingen konden de concept map gedurende het onderzoekend leerproces steeds bijstellen. In de leeromgeving opgedane kennis kon op deze manier eenvoudig worden verwerkt in de concept map.

In het onderzoek worden twee groepen vergeleken, een controle groep die beschikking had over een leeromgeving met ondersteuning door een gedeelde propositie tabel en een experimentele groep die naast de propositie tabel ook de beschikking had over een concept mapping tool. De leerlingen werden voor en na de interactie met de leeromgeving getoetst op intuïtieve kennis. Daarnaast werden leerlingen voor en na de sessie gevraagd een essay te schrijven over een domein gerelateerd fenomeen. Leerlingen in beide condities boekten leerwinst. De leerwinst van leerlingen die ondersteund werden met behulp van een concept map was hoger dan die van de leerlingen in de controle conditie.

Analyse van de interactie protocollen gaf aan dat leerlingen in de concept mapping conditie meer opmerkingen maakten die gerelateerd waren aan het doen van experimenten. Analyse van de logfiles gaf echter aan dat leerlingen in de controle conditie meer experimenten hebben uitgevoerd. Dit suggereert dat leerlingen in de concept mapping conditie de uitgevoerde experimenten intensiever bespraken dan de leerlingen in de controle conditie. In de concept mapping conditie werd een positieve relatie gevonden tussen het percentage communicatie gericht op het bespreken van experimenten en de resultaten op de essay vraag.

Terugblik

Terugkijkend op de drie studies die worden besproken in het kader van dit onderzoekstraject kan worden geconcludeerd dat samenwerking een positieve invloed kan hebben op het onderzoekend leerproces. Het is daarbij echter wel van belang dat de individuele voorkennis van de samenwerkende leerlingen voldoende mogelijkheid tot discussie en elaboratie biedt. Verschillen in voorkennis en mening kunnen een positieve impuls vormen voor het samenwerkend onderzoekend leerproces. Leerlingen zijn zich echter niet altijd bewust van de verschillen tussen hun eigen voorkennis en die van hun partner. Het is dan ook van belang dat leerlingen tijdens het leerproces hun eigen ideeën en meningen verbaliseren zodat deze kunnen dienen als startpunt voor het leerproces. De verschillende vormen van ondersteuning die zijn ontwikkeld in het kader van het beschreven onderzoekstraject beoogden de discussie omtrent het formuleren en testen van proposities te ondersteunen. Zowel de gedeelde propositie tabel als de concept mapping taak bleken de externalisatie van domeinkennis en ontdekkend leerprocessen te stimuleren. Leerlingen in de experimentele conditie van het derde onderzoek (ondersteund met een gedeelde propositie tabel en een concept mapping tool) presteerden het beste op de kennistoetsen. Het is echter niet duidelijk in hoeverre deze resultaten zijn toe te schrijven aan de concept mapping taak of aan de combinatie van de concept mapping taak en de gedeelde propositie tabel.

Het gedeelde propositie kladblok (tweede studie), bleek minder geschikt voor het in korte tijd bespreken van verschillende proposities en de acquisitie van intuïtieve domein kennis. De beperkte tijd die beschikbaar was voor interactie met de leeromgeving (en het propositie kladblok) heeft mogelijk een negatief effect gehad op de manier waarop leerlingen met het kladblok hebben gewerkt. De beperkte tijd zorgde ervoor dat er weinig tijd was om te leren omgaan met de tool. Inspectie van de logfiles en interactie protocollen van leerlingen die met propositie tabel hebben gewerkt geven aan dat deze leerlingen veel tijd hebben besteed aan het bespreken van de structuur van de verschillende beweringen. Het zou dan interessant zijn om te onderzoeken of leerlingen die worden ondersteund met behulp van een propositietabel meer onderzoeksvaardigheden opdoen tijdens het leerproces.