# Confronting ideas in collaborative scientific discovery learning

Hannie Gijlers, Ton De Jong

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# Sharing and Confronting Propositions in Collaborative Scientific Discovery Learning

Hannie Gijlers

and

Ton de Jong

University of Twente

Faculty of Behavioral Sciences

Department of Instructional Technology

P.O.Box 217

7500 AE Enschede

The Netherlands

0031 53 489 4074

## Abstract

This study investigated how collaborative knowledge construction within a scientific discovery (or inquiry) 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. All students completed a proposition test 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 pre-defined 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 intuitive knowledge and proposition pre- and post-tests.

The findings indicate that students supported with the shared proposition table improved significantly from pre- to post-test and discussed significantly more alternative propositions.

# Sharing and Confronting Propositions in Collaborative Scientific Discovery Learning

Inquiry learning in simulation environments is a highly self-directed way of learning (1998). Within such type of learning environments students try to find characteristics of the model underlying the simulation through experimentation (Friedler, Nachmias, & Linn, 1990). Swaak and de Jong (1996) hypothesize that knowledge that students obtain in inquiry learning environments has a more intuitive character and is better anchored than knowledge that is gained from traditional lectures.

Besides having advantages, inquiry 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. Therefore, it is now generally concluded that unsupported discovery learning is not effective (de Jong & van Joolingen, 1998; Mayer, 2004). 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 inquiry learning with computer simulations. We describe tools that are designed to stimulate meaningful interaction between students and that support them during the inquiry learning process. Before zooming in on collaborative inquiry learning in computer based simulation learning environments we first discuss aspects of inquiry and collaborative learning.

*Scientific discovery or inquiry learning*

Scientific discovery or inquiry learning is a complex process in which a number of specific learning processes can be distinguished. In literature many classification schemes for inquiry learning can be found (see e.g., Kuhn, Black, Keselman, & Kaplan, 2000; Njoo & de Jong, 1993;

White, Shimoda, & Frederiksen, 1999). Most classification schemes distinguish similar processes, which are quite similar to the processes distinguished in the empirical cycle (de Groot, 1969). The classification scheme used in this article is based on the work by de Jong and Njoo (1992). De Jong and Njoo (1992) distinguish between transformative processes (processes that directly yield knowledge), and regulative processes (processes that are necessary to control the inquiry learning process). Transformative processes include: *orientation, hypothesis generation*, *experimentation*, and *conclusion* Regulative processes include *planning*, and *monitoring*. An overview of these processes is presented in de Jong (in press).

During *orientation* students identify the variables, and parameters in the model, and indicate general properties of the model. During orientation students form an idea of the structure and the complexity of the domain at hand. For students with limited prior domain knowledge it is often difficult to recognize important variables, and potentially interesting relations. *Generating a hypothesis* is regarded as one of the central processes in inquiry learning. In a hypothesis 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. 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 study described in this article students are asked to discuss, and investigate the truth-value of statements concerning the relation between variables. For this reason we chose to use the term proposition generation instead of hypothesis generation. 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. *Experimentation* includes designing experiments, predicting the outcome of an experiment, and collecting data. Students might experience difficulties with the translation of a proposition into an experiment. Schauble, Glaser, Raghavan, and Reiner (1991) found that students often perform experiments that are not suited to test the intended proposition. During interpretation students try to make sense of the experimental data. Research indicates that students often lack the skills that are needed to interpret data like reading graphs and extracting information from tables (Beichner, 1994; de Jong & van Joolingen, 1998). In the *conclusion* phase students review their hypothesis in the light of the experimental data they collected during the experimentation phase. For successful inquiry learning not only the transformative processes but also the regulative processes are important. Various studies have shown that successful students as compared to unsuccessful 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, do not keep track their prior experiments into account, and are weak in regulating their inquiry process (Quintana, Zhang, & Krajcik, 2005).

Supporting students in the process of inquiry learning by means of cognitive tools or scaffolds is the subject of many studies (see, for example, de Jong, in press; de Jong & van Joolingen, 1998; Linn, Bell, & Davis, 2004; Quintana et al., 2004). Often these scaffolds focus on the process of individual inquiry. Support can, however, also be found in working together with a fellow student through collaborative learning.

*Collaborative learning*

There is a growing awareness that knowledge construction processes are influenced by the social setting in which they take place. Knowledge construction often is a social process, and can be described as a social cognitive process, were students co-construct knowledge. Collaboration is widely used and recognized as a way to enhance the learning of students (Lou, 2004; Lou, Abrami, & d'Apollonia, 2001). 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. Different combinations of prior knowledge within dyads or groups may lead to differences in learning, and interaction processes. Within heterogeneous groups both the more able and less able students might benefit from the differences in prior knowledge and ability. The less able students can benefit from the guidance, and explanations provided by the more able students and students with higher levels of prior knowledge, and ability progress through the cognitive restructuring involved in peer tutoring (Webb, Nemer, & Zuniga, 2002). In order to communicate ideas and explanations, students are requested to recapitulate their own understanding of the task or phenomena. Externalization of ideas and thoughts students can raise students; awareness of their own ideas and reasoning processes and might even help them detect defects in their understanding (van Boxtel, van der Linden, & Kanselaar, 2000). The responsibility that students feel for providing clear explanations to their partners helps them to gain greater conceptual clarity for themselves (Damon & Phelps, 1989). In a collaborative learning setting students might experience that their own ideas and knowledge differ from the knowledge and ideas their partner holds. Confrontation with information, data or experiences that contradict students' initial understanding of a task or phenomenon may lead to a state of disequilibration, students might experience a so-called cognitive conflict. The effort that students take to overcome this state of disequilibration facilitates learning (Piaget, 1985). The neo-piagetian term socio-cognitive conflict refers to a situation where a controversy between the viewpoints and ideas of collaborating students appears. Doise and Mugny (1979) argue that cognitive conflicts in itself may contribute to positive learning effects but that cognitive conflicts appearing in social setting are even more significant. In social settings (such as a collaborative learning setting) resolving the conflict is not only important for the learning process of the individual, but is also important with respect to the collaborative relationship. The mere presences of contradicting ideas between partners, however, does not necessarily enhance learning (Damon & Phelps, 1989). Perret-Clermont (2004) agrees that contradicting ideas do not necessarily lead to (intellectual) arguments. In order to benefit from a socio-cognitive conflicts students have to detect these conflicts, reflect on them and be prepared to resolve the contradiction (Nastasi & Clements, 1992). Webb and Palincsar (1996), found that elaborated explanations and discussions are mediating learning, when students only provide short answers and explanations learning is not enhanced by collaboration. Similar results are reported by Chan (2001), who investigated the effects of collaboration and discourse patterns on conceptual change. The results of her study indicate that conflicts were of limited use unless they were accompanied by co-construction activities.

In summary social cognitive conflicts provide important opportunities for learning. These conflicts involve the confrontation with a partner who holds different viewpoints or proposes a different solution for the same problem. Collaborative learning tasks that allow students to express and explore differences in opinion provide opportunities for cognitive conflicts. Inquiry learning tasks allow students to express and explore their own strategies and conceptions; in a collaborative inquiry learning setting students are invited to share these plans and ideas with their partner(s). The present study investigates the effects of collaboration in an inquiry learning setting and explores how constructive collaboration can take place through argumentation and co-construction activities.

*Collaborative inquiry learning*

Combining inquiry learning with collaboration seems a promising approach to help increase the effectiveness of inquiry learning. Collaboration provides students' with opportunities to discuss their ideas, the design of their experiments and the experimental outcomes with others. This provides opportunities for the above mentioned cognitive conflicts as well as co-construction and elaboration. Kaartinen and Kumpulainen (2002) investigated the construction of students' explanations of solubility in a collaborative inquiry learning setting, and found that students combined informal and formal explanations. An analyses of students’ pre-test and post-test results and the collaborative discourse indicated that the collaborative learning setting provided students with opportunities to elaborate their explanations, build their own theories, and stimulated reflection (Kaartinen & Kumpulainen, 2002). Collaborative inquiry does not only stimulate elaboration but also helps students to consider alternative viewpoints. Okada and Simon (1997) compared the collaborative inquiry 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 pairs engaged in more exploratory activities and eventually were more successful at the inquiry learning task than the singles. Results of other studies provide evidence that in a collaborative learning group students often serve as a sort of supervisor for each other. The observe what other group members are doing and use this information to check their actions and might even prompt them to rethink their actions and interpretations (Miyake, 1986).

*Computer supported collaborative inquiry learning*

Computer supported simulation environments are specifically suited for inquiry learning (de Jong & van Joolingen, 1998). Computerized simulations environments contain a simulation of real world processes. Within these simulation environments student can actively construct knowledge through experimentation with the simulation. With modern computer supported communication technology, the simulation environments can be adjusted for collaborative learning settings. In the present study students worked with such a simulation based collaborative inquiry learning environment. Computer supported collaborative learning involves computer mediated communication. In a face to face setting gestures and facial expressions partly mediate the coordination. In a face to face setting a facial expression often communicates whether the partner understood a certain explanation or agrees with the plan. In computer supported collaborative learning through a chat channel these visual clues are absent (Ruberg, Moore, & Taylor, 1996)and coordination and the communication have to be performed in more explicit ways(Rummel & Spada, 2005). Computer mediated communication also has a number of advantages that are important for collaborative knowledge construction. In computer mediated learning environments students’ messages can be logged and stored for later consultation. This allows students' to reflect and build on earlier responses. Furthermore, computer supported collaborative learning environments often contain shared tools and representations. Sharing tools and representations can help students to coordinate their learning process and maintain a shared perspective on the task (Suthers, Hundhausen, & Girardeau, 2003; Veerman, Andriessen, & Kanselaar, 2000). In a collaborative inquiry learning setting students share tools and reference materials like graphs and tables on a computer screen. Changes made by one students are directly visible for the others students. Suthers and Hundhausen (2003) found that when students change a shared representation they feel the need to discuss this with their partner, this has a positive effect on the coordination in a computer supported learning context. Therefore, it seems likely that the introduction of shared representations will have a positive influence on the computer supported inquiry learning process.

*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. In a previous study Gijlers and de Jong (2005).explored the collaborative inquiry learning process of dyads of students who worked together on an inquiry learning task in the physics domain of motion. The interaction protocols of the exploratory study revealed only a few cases where students verbalized relations between variables in the domain. This limited amount of externalized propositions decreases the likelihood that a profound discussion about domain related propositions will arise. Because the generation of propositions is such a crucial phase in the whole inquiry 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.

Discussion between learners 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. Prompting students to state a proposition might stimulate students to formulate a proposition but does not assist students with the process of building testable propositions. Previous studies revealed that students find it difficult to compose syntactically correct and testable propositions (Njoo & de

Jong, 1993; van Joolingen & de Jong, 1997). 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 to support students 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. This study also showed that students choose different routes through a list of proposition. The tools designed by van Joolingen and de Jong (1991) 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 is expected 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 inquiry environment, that are designed to support dyads of students during their inquiry 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.

# Method

## *Domain and Learning environment*

The learning environment in this study was called Motion and covered the physics domain of one dimensional kinematics. The learning environment was designed to help student develop insight in issues related to moving objects and deals with velocity, acceleration, distance covered, force, and friction. The simulation within the environment allowed students to change input variables and observe the behavior of output variables. Model progression (White & Frederiksen, 1990) was used to create a step-wise introduction to the model. The basic idea behind using model progression is that students might be overwhelmed by the model in its full complexity. By moving through intermediate steps (or levels) with increasing complexity the students gradually learn the full model. The learning environment used in this study contained three levels of complexity. 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 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.

**Insert figure 1 about here**

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 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 for 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 later during the learning process. The proposition scratchpad was combined with a chat tool, where students could, for example, 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 2, a screenshot of the proposition scratchpad is presented.

**Insert figure 2 about here**

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). Together 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 for collaborating students, displaying the individual markings of both students (see Figure 3). Differences in opinion were stressed by the use of color. 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 ‘simulation’) and in that case they were provided with a simulation state and an assignment that was suited to test this particular proposition.

**Insert figure 3 about here**

*Subjects*

Sixty-six subjects participated in the study. They were fourth year students from secondary education, aged 15-16. All students had completed an introduction in the domain of kinematics that covered the domain knowledge needed in the simulation environment. With respect to the composition of dyads we decided to make heterogeneous groups based on students’ school achievement in the domain of physics (this information was provided by the participating schools). This grouping was based on the finding that heterogeneous grouping is beneficial for both high and low achieving students (Webb et al., 2002). The dyads were randomly assigned to one of the three conditions such that each condition contained 11 dyads. Subjects participated in the experiment on a voluntary basis and received a small reward for their participation. All subjects had computer experience.

*Tests*

Three test were administered, a definitional knowledge test, an intuitive knowledge test (‘what-if” 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; the intuitive and proposition test were administered as pre- and posttest.. No significant correlations were found between the three (pre-) tests. This suggests that the tree test assessed different aspect of knowledge.

*Definitional knowledge test*

The definitional knowledge test focused on students’ definitional knowledge and contained questions about concepts, formulae, and definitions that are relevant for the simulation (two examples are provided in Figure 4). 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.

**Insert figure 4 about here**

*“What- if” test*

Working with a inquiry 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. Each question in the “what-if” test consisted of three parts; conditions, actions and predictions (an example is presented in Figure 5). 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. The pre- and post-test version of the test where equivalent, both versions consisted of the same items. However, the order of the items and answer alternatives differed in both versions of the test. Cronbach’s alpha yielded .76 for the pre-test and .72 for the post-test which can be interpreted as good.

**Insert figure 5 about here**

*Proposition test*

A proposition test focused on students' knowledge 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 propositions were true, possibly true, possibly false, or false. Third, the students indicated if they considered testing the presented proposition. The proposition test was computer administrated. Students' individual responses on the proposition test were saved and used as a source of information for the shared proposition table. An example-item from the proposition test is displayed in Figure 6. When dyads in shared proposition table condition entered the collaborative inquiry learning environment their individual tables were combined in a shared proposition list that displayed the truth-values assigned by both students. An example of the shared proposition list was presented in Figure 3.

**Insert figure 6 about here**

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. The contained the same propositions in a different order. Furthermore, with each proposition in the post-test version students only had to assign a truth-value to the presented propositions. Students’ test score on the proposition test was calculated as the total number of propositions the students correctly identified as true or false.

*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.

*Process analysis*

This study focuses on collaborative knowledge construction in an inquiry learning setting and the effect of supportive measures on the collaborative inquiry learning process and learning outcomes. As stated in the introduction learning by inquiry requires that students engage in a number of inquiry learning processes. In order to investigate the influence of the supportive measures on the inquiry learning processes we decided to code and analyze students interaction in terms of the inquiry learning processes (Gijlers & de Jong, 2005).The chat logs were coded in terms of inquiry learning processes (see Table 1). 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 and was further analyzed. As indicated in the introduction we distinguished the following transformative processes; orientation, proposition generation, experimentation, and conclusion. During the test phase of the coding scheme we noticed that it was difficult to make a clear distinction between data-interpretation (part of the experimentation process) and conclusion. Students often combined these two in one utterance. Students made a comment about their experimental outcomes and based on these comments they drew a conclusion about the proposition. Utterances coded as conclusion may contain some elements of data-interpretation and therefore we think the label interpretation and conclusion is more appropriate in this particular learning session. A second coder coded about 10 percent of the data. Table 1 provides examples of utterances coded in terms of inquiry learning categories. 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 asses how many different propositions the students generated and discussed during their learning session.

**Insert table 1 about here**

## Results

In this section we first report the differences among conditions based on scores on the knowledge tests, followed by an overview of the differences between conditions on the process variables. Subsequently, we will present correlation results. Finally, we present excerpts from students’ chat conversation to illustrate the collaborative inquiry learning process and students’ interaction during this process.

### *Differences between conditions*

Three tests were administered; a prior definitional knowledge test, and, both as a pre-test and post-test, an intuitive knowledge test and a proposition 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 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. As group heterogeneity is an important factor in collaborative learning settings, we tested whether there were significant differences between conditions on the heterogeneity of dyads. The score difference between partners (score of student A minus score of student B) served as an indicator for heterogeneity. For each dyad the score difference on the three pre-tests was calculated. No significant differences on group heterogeneity over the three conditions was found: (definitional knowledge: ($F_{(2, 30)}$ = .779, $p$ = .468), intuitive knowledge ($F_{(2, 30)}$ = 1.154, $p$ = .329), proposition test ($F_{(2, 30)}$ = 2.052, $p$ = .146).

Table 2 provides an overview of the mean scores on the definitional domain knowledge test, the “what-if” test and “proposition” test for the three conditions. To examine the differences in achievement between students in the three conditions an analysis of variance based on the students’ learning gains (post-test scores minus pre-test scores) with the scores on the definitional domain knowledge test as a covariate was performed. For the “what-if” test the results showed no significant effect for prior definitional domain knowledge ($F(1, 62) = .078$, $p>.05$) and a significant effect for condition ($F(2, 62) = 9.225$, $p<.00$) on learning gains. In Table 2 an overview of the number of correctly identified propositions is provided. An ANCOVA based on students' gain scores on the proposition test with the scores on the definitional knowledge test as a covariate showed no significant effect for prior definitional domain knowledge ($F(1, 62) = 1.06$, $p>.00$) and a significant effect for condition ($F(2, 62) = 6.675$, $p<.05$). The results of Scheffe pairwise comparison on the adjusted means (controlled for prior definitional knowledge) showed significant differences on learning gains in favor of the shared proposition table. Significance differences were found on learning gains between the shared proposition table condition and both the scratchpad and control condition.

**Insert table 2 about here**

*Process analyses*

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. We analyzed process variables as frequencies and as percentages of the total interaction. Since these two procedures yielded similar results, we present only analyzes based on the percentage of total interaction. 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 on the overall number of utterances were found between the three conditions. Significant differences between conditions were found for 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 the students in the control condition.

Inspection of chat files revealed that some students devote a large amount of utterances to one proposition whereas 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. An ANOVA with the number of unique propositions as the dependent variable revealed a significant difference between conditions ($F$ (2, 30) =26.82, $p$< .00).

**Insert table 3 about here**

Tukey HSD multiple comparisons post hoc test showed significant differences, concerning the number of unique propositions, between the shared propositions table and both other conditions. These results suggest that students in the shared proposition table condition covered a larger part of the domain than students in both other conditions.

*Correlational results*

In this section we present the results a correlational analysis investigating the relation between students’ test scores and the communication in terms of learning process categories. Negative correlations were found between the percentage of technical communication and the post-test and gain test scores on the “what-if” if test and the post-test scores of the proposition test. This indicates that students who frequently discussed technical aspect (these are students who often have problems with operating the learning environment) gained less intuitive knowledge. A negative correlation was also found between the percentage of utterances related to orientation and the scores on the (pre-test) definitional knowledge test (Table 4). This indicates that students with higher scores on the definitional knowledge test made fewer utterances related to orientation.

Positive correlations were found between the percentage of utterances related to interpretation and conclusion 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 and conclusion. We also found a positive relation between students’ scores on the “what-if” pre- and post-test and the percentage of transformative utterance made by the students. No significant correlation was found between the learning gain on the “what-if” test and the percentage of the transformative utterances. A partial correlation between “what-if” post-test scores controlling for the pre-test scores also revealed no significant correlation. This suggest that the correlation between the post-test scores and the percentage of communication students spend on transformative processes is explained by students pre-test scores on the “what-if” test.

**Insert table 4 about here**

Regression analysis with the learning gains on the “what-if” test as dependent variable and the scores on the definitional knowledge test and learning process categories as independent variables resulted in non significant results. The same holds for a regression analysis with the learning gains on the proposition test as a dependent variable and the scores on the definitional knowledge test and learning process categories as independent variables. Over all conditions, a negative correlation ($r = -.488$, $p<.01$) was found between the percentage of agreement between the two working partners working together (calculation based on the results of the proposition pre-test) and the number of unique propositions discussed during the learning session.

*Case analyses*

The previous presented quantitative analyses indicate that students who were confronted with each others (possibly contradicting) opinions concerning the truth-value of a list predefined propositions improved significantly from pre- to post-test. Students in both the control and shared proposition condition did not improve significantly from pre- to post- test. To understand if and how the role of collaboration, confrontation and co-construction contributed to the presented learning outcomes, we presents six excerpts from protocols that provide examples of students knowledge construction process in the different conditions. For each condition we selected two example excerpts of dyads with different levels ability.

*Discovering the domain without support.*

*Example excerpt 1: Exploring the domain and the learning environment*

In the following excerpt Mary and Eve are working on the first level of the learning environment. Mary is an average achieving student and Eve is a low achiever. In this excerpt they are trying to identify important variables and try to make plans.

**Insert table 5 about here**

In the first turns (1, 2, 3, and 4), Mary and Eve introduce themselves. After a short introduction they immediately move on the task and start making plans (turn 5, 6, and 7). They inspect the learning environment and start to discuss variables that are available in the learning environment (turn 8, 9, and 10). They continue inspecting the environment and explore the graph and they output field by changing a variable and observing the effects (turn 13 to 19). Their communication suggests that changing the parameter was not intended to test a proposition but just to inspect how the learning environment works. The communication of Mary and Eve is typical for students who enter the learning environment. In this excerpt Mary and Eve spent a large proportion of utterances on orientation (inspecting variables and the learning environment) and on regulation starting up the process by discussing what to do (turn 7) and how to continue (turn 21 to 23). Regulation and coordination are important in this phase of the collaboration because Eve and Mary have to establish a shared focus on the task in order to maintain a successful collaborative relationship.

*Example excerpt 2: Working your way through the environment*

The excerpt is taken from the chat log of Martin and Jenny. Martin is an average achieving student and Jenny is a high achieving student. Both students worked with the unsupported version of the learning environment. In this episode Martin and Jenny work on assignments from the third and last level of the learning environment and finish their work.

**Insert table 6 about here**

The communication between Martin and Jenny suggests that they are very focused on completing the task. Their communication is characterized by regulative remarks (turn 2, 5, and 6) and utterances that refer to assignments and answers (turn 4, 5, and 8). Their main shared focus seems to be completing the learning task. Martin and Jenny do not discuss the assignments, their answers or the feedback provided by the simulation. When Jenny (turn 7 and 8) notices that the simulation does not produce the expected results, they simply conclude that their solution was wrong and continue with another assignment (turn 9 and 10).

The interaction of Mary and Eve, as well as Jenny and Martin illustrate that students’ task perception is an important factor in a collaborative inquiry learning environment. The excerpt of Mary and Eve is characterized by orientation on the task and environment. Mary and Eve just start collaborating and inspect the environment in order to build a common understanding of the task. Jenny and Martin clearly do not perceive understanding the simulated domain as their main task but focus on finishing the assignments that are available in the learning environment. In finishing the assignments their focus is not on understanding the assignments and providing qualitative solutions but on completing them as soon as possible.

### *Constructing propositions with the shared proposition scratchpad*

#### *Example excerpt 1: Trouble with the scratchpad*

In this chat episode we present the dialogue of Alexander and Jonah, a low and average achieving student. This excerpt illustrates that constructing a proposition is especially difficult when you have access to a limited amount of prior knowledge. Both students find it difficult to recognize interesting relations within the domain. Their limited knowledge of variables and constructs.

**Insert table 7 about here**

Alexander and Jonah clearly find it difficult to construct a proposition. The fact that Alexander in turn 11 remarks that they should have an idea suggests that the students are aware of the fact that they are lacking some prior knowledge. Alexander and Jonah are actively searching the learning environment for clues. They open the pull down menu to search for variables (turn 5). The information provided in the pull down menus does not make sense to them. Jonah talks about the “s” variable (turn 13). Again Alexander seems to notice their limited prior knowledge (turn 14 and 15). Jonah decides not to give up and suggests searching the environment again. Returning to the environment Alexander notices something familiar (turn 20).

The communication between Alexander and Jonah shows that both boys focus on the task. The fact that Alexander and Jonah are respectively a low and average achieving students hinders their process of knowledge construction with support of the shared proposition scratchpad. The excerpts illustrate that in order to operate the scratchpad and actually build a proposition students have to be able to select potentially interesting variables (process of orientation). Jonah and Alexander lack this prior knowledge and try to find clues in the learning environment that will help them in the process of selecting variables in order to construct a proposition. The interaction between Alexander and Jonah is characterized by a large number of utterances related to orientation and the construction of proposition. Because the process of constructing a proposition is a difficult process, only a limited amount of time is left for testing the proposition.

*Example excerpt 2: Constructing a proposition, prior knowledge is a pre*

In this excerpt we present the dialogue, two students working with the shared proposition scratchpad; Anne and Ester. Anne is an average achieving student and Ester a high achieving student (based on the opinion of their teacher and their pre-test scores).

**Insert table 8 about here**

Together Anne and Ester have access to a large base of domain information. This is reflected in their communication. They use the terms distance covered and acceleration with ease (turn 1, 2, and 3). The fact that Anne uses the phrase is getting larger (turn 3) suggests that Anne has some idea of how to formulate a proposition. Anne and Ester are building on each others comments. Based on the terms acceleration and distance covered proposed by Anne (turn 1), they explore the relation between those variables (turn 3, 6, 7, 8 and 9). Anne and Ester conclude (turn 8 and 9) that if acceleration increases the car will drive faster. Anne and Ester continue that driving faster also means that more kilometers will be covered within a certain amount of time (turn 12 and 13). In the last turn Anne return to the scratchpad by stating that their conclusion should be written down in the table. The scratchpad triggered Anne and Ester to explore and discuss their ideas concerning acceleration and covered distance. In contrast to Jonah and Alexander who used the learning environment as a source of information, Anne and Ester consulted their prior domain knowledge and build on and refined each others comments.

The excerpts presented in table 7 and 9 suggest that constructing a proposition with the shared scratchpad is still a difficult and time consuming process. In order to construct an interesting proposition students inspect their initial prior knowledge as well as the learning environment for potentially interesting variables and relations. Alexander and Jonah as well as Anne and Ester thoroughly discuss variables and relations. The shared environment, task and scratchpad served as a center for coordination.

*Discussing and testing propositions from the shared proposition table*

*Example excerpt 1: Let’s test it!*

Annetta and Joseph are respectively a high and average achieving student. They are working on the first level of the learning environment and discuss a proposition the following proposition “If the initial velocity of an object without acceleration doubles then the final velocity of the object also doubles”.

**Insert table 9 about here**

Annetta and Joseph start their discussion from a case of disagreement. Joseph thinks the proposition is not true (turn 1). Annetta suggests testing it with the simulation (turn 2) and continues to convince Joseph by providing an example (turn 3 and 4). Joseph’s response to her example suggests that he understands what she is talking about. They decide to run the simulation (turn 7). Annetta reacts that it seems true, but Joseph notices that the graph and Annetta's opinion are not agreeing with each other. The line in the velocity versus time diagram is getting steeper and is not the expected flat line. Annetta quickly responds that he doubled the acceleration instead of the initial velocity (turn 10). She continues explaining that if the acceleration is zero will move at a constant speed. Joseph seems convinced; he even completes her explanation (turn 12). In order to check their understanding they decide to run the simulation again (turn 13). Joseph seems to agree with Annetta that the proposition is true, in turn 14 he states “Ok, we were right”. Annetta suggests they should test another proposition (turn 15).

*Example excerpt 2: Who is right?*

In Table 10 we present an excerpt from the communication of William and Sandra, both average achieving students. William and Sandra discussed a number of propositions from the second level and decide to move on the third level of the learning environment. William and Sandra start discussing the following proposition: Acceleration is directly proportional to mass (if force is held constant). This proposition is not true. Subsequently, they discuss which truth-value should be assigned to the proposition: Acceleration is directly proportional to net force (if mass is held constant).

**Insert table 10 about here**

In turn 1 to 4 William and Sandra are coordinating their actions. The statement made by William suggests that he selects a proposition (turn 5) for further investigation. Sandra responds to his statement, by presenting her own opinion (turn 6) and proposing to test the proposition. Sandra and William start experimenting. Sandra seems to be coordinating the first experiment by reminding William that it is important to save the graph (turn 11 and 13). The results indicate that Sandra assigned the right truth-value to this particular proposition. William and Sandra don’t discuss this. They just observe the changes in the graph and move to the next proposition. William (turn 16) selects another proposition on which both students disagreed. He directly tells that they should test it (17), but then continues to reformulate the proposition (turn 18). Sandra does not seem to agree fully with his reformulation (turn 19, 20, 22). Sandra introduces the term acceleration (turn 19). But Sandra’s statements about acceleration are not further investigated. To Sandra it is clear that that acceleration doubles if Force doubles and mass is kept constant. She does not successfully communicate her ideas to William. In turn 23 William tells Sandra he could have told her. This suggests that William and Sandra are not focusing on the same aspects of the experimental outcomes. This could be explained by the fact that Sandra is focusing on acceleration while William talks about velocity.

In both excerpts students discussed propositions in a relative small number of utterances. This is typical for students working with the shared proposition scratchpad. William and Sandra seemed to rush towards some sort of agreement, and often focused on different aspects of the same proposition. In discussing the second proposition Williams reformulation of the proposition does not fully reflect the proposition provided by the environment. Sandra notices but does not successfully correct him. Annetta’s and Joseph’s discussion seemed more successful; they complete each others remarks and seem to reach a common understanding. The examples provided in Table 9 and 10 illustrate that confrontation alone does not foster understanding (Damon & Phelps, 1989). Actually experiencing a conflict, analyzing it and solving it is more important. In order to solve a cognitive conflict students have to understand each others point of view (Forman & Cazden, 1985).

## *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' inquiry 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, Mugny, & Perez, 1998). In order to benefit from a partners' alternative beliefs students have to maintain a common focus and be aware of the differences in their ideas (de Vries et al., 2002).

To investigate how students could be supported during the process of collaborative inquiry learning and more specifically the generation of propositions, three version of the same learning environment were compared. In the first (control) version contained no extra support related to proposition generation or testing. In the second version students were supported with a proposition scratchpad, and in the third version of the environment students worked with a shared proposition table. 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). The fact that students had to construct their own propositions and thus select the relevant variables, relations and restrictions possibly explains why these students have discussed less unique propositions. The presented log files suggest that formulating a proposition with the scratchpad maintained a difficult and time consuming task for students. The log files also indicate that students who collaboratively constructed a proposition had the opportunity to discuss relevant variables, relations, restrictions and the format of a sound proposition in detail.

In conclusion, the findings of the study suggest 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 was significant but not very large. We can think of a number of reasons for this. First, the students worked with the simulation environment for a short and limited period and focused on resolving differences in opinion. Elaborated responses and mutual efforts to understand each others opinions are important factors influencing the outcomes of collaborative learning inquiry processes. Within the limited timeframe students might have quickly gone to an agreement without fully understanding their partners' point of view. Second, students discussed individual proposition as if they were unrelated to previously discussed propositions. Students did not make connections between the various propositions and hardly connected their findings to their existing knowledge base. For successful collaborative inquiry learning it is important students' not only externalize their own opinions and ideas but connect their ideas to existing knowledge (Muukkonen, Lakkala, & Hakkarainen, 2005)

Further research could focus more on the integration of the constructed knowledge within the framework of the students’ existing knowledge base. A possible way to support students’ reasoning about relations between variables in the simulated domain is to combine inquiry learning with a qualitative or quantitative modeling tool. In the inquiry learning task students’ explore the simulated domain through experimentation. A modeling tool provides students the opportunity to express their newly obtained knowledge in terms of relations (Löhner, van Joolingen, & Savelsbergh, 2003). Computer supported run able modeling tools allow students to observe the outcomes of their own model and compare it with the output of the model provided by the simulation environment.

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Table 1

*Overview and examples or the inquiry learning process codes*

| **Categories** | **Examples from students interaction** |
|---|---|
| Off task | ‘ He, I really like the skirt Sandra is wearing today’ |
| | ‘Did you also go to the concert last Saturday?’ |
| Technical | ‘I cannot see the chat window’ |
| | ‘Can you move the chat window to the right’ |
| Regulative | ‘We have 20 minutes left and we are still working on the first level, lets skip to the next’ |
| | ‘Do you agree with me on this idea’ |
| Transformative | |
| *-Orientation* | ‘Look at the line it is not |

| | |
|---|---|
| | straight but a curve’ |
| | ‘What does this N next to mass mean’ |
| *-Proposition generation* | ‘If the initial velocity increases the final velocity will also increase’ |
| | ‘I think acceleration is negative, when you are slowing down’ |
| *-Experimentation* | ‘I think it is a good idea if we test this idea’ |
| | “Lets see what is changing if we double the acceleration’ |
| *-Interpretation and conclusion* | ‘Ok why is the line a curve’ |
| | ‘It seems like our car is moving faster now’ |
| | ‘So the line is steeper, we can see that speed is increasing fast’ |

Table 2

*Means and standard deviations (between brackets) on the knowledge tests*

| Condition | N | Definitional knowledge | What- if test | | Proposition test | |
|---|---|---|---|---|---|---|
| | | | Pre - test | Post-test | Pre-test | Post-test |
| Control condition | 22 | 14.59 (3.14) | 14.00 (2.00) | 14.13 (1.69) | 9.32 (3.99) | 9.77 (3.92) |
| Scratchpad | 22 | 15.50 (3.32) | 14.50 (2.35) | 14.31 (2.50) | 7.86 (2.87) | 7.36 (3.18) |
| Shared table | 22 | 15.13 (2.71) | 13.77 (1.79) | 15.22 (2.13) | 8.23 (3.85) | 11.00 (3.40) |

Table 3

*Overview of the number unique propositions discussed in 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 | 11 | 14.56 | (9.80) | 2.82 | (1.78) |
| Scratchpad | 11 | 16.85 | (8.05) | 7.82 | (3.25) |
| Shared proposition table | | | | | |

Table 4

*Correlations between process measures and “test scores”*

| | domain | “what-if” pre | “what-if” post | “what-if” gain | Prop pre | Prop post | Prop gain |
|---|---|---|---|---|---|---|---|
| Technical | .033 | .093 | -.128 | -.311* | -.159 | -.248* | -.092 |
| Regulative | -202 | .139 | .190 | .080 | .068 | .116 | .084 |
| Transformative | .020 | .257* | .263* | .022 | .037 | .019 | .032 |
| - Orientation | -.363* | .198 | .206 | .023 | .160 | .092 | .092 |
| -Prop generation | .188 | .153 | .262 | .165 | -.017 | .098 | .215 |
| - Experimentation | .100 | .123 | .031 | .031 | -.054 | -.054 | -.054 |
| - Interpretation and | .252* | .114 | .211* | .132 | -.096 | .030 | .220 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| conclusion | | | | | | | |
| Unique propositions | -.047 | -.085 | .129 | .301* | -.164 | .178 | .406* |

* $p < .05$

** $p < .01$

Table 5

*Example episode form the chat-communication of Anne and Joseph*

| Turn | Student | Chat message |
|---|---|---|
| 1 | Mary | Who are you? |
| 2 | Eve | Eve |
| 3 | Eve | And who are you? |
| 4 | Mary | Mary |
| 5 | Eve | Okay Mary lets read |
| 6 | Mary | Yip right |
| 7 | Eve | What is our plan? What are we going to test? |
| 8 | Mary | Well lets see there is initial speed |
| 9 | Eve | We can change the initial speed that’s right |
| 10 | Eve | And we also can change the acceleration |
| 11 | Mary | She (referring to the leader of the experimental session) said that we could observe the effects |

| | | |
|---|---|---|
| 12 | Mary | In the graph |
| 12 | Eve | But what to observe? |
| 13 | Mary | Let’s try something just to see how |
| 14 | Eve | Hop see I enlarged this |
| 15 | Mary | Start |
| 16 | Mary | Okay, you see it moving |
| 17 | Mary | And the numbers run |
| 18 | Eve | It’s a straight line |
| 19 | Mary | There you have time in the graph |
| 20 | Eve | Yeah |
| 21 | Eve | Do you know what to do next |
| 22 | Eve | Well an assignment |
| 23 | Mary | Take a look at 1.1 |

**Table 6**

*Example episode form the chat-communication of Martin and Jenny*

| Turn | Student | Chat message |
|---|---|---|
| 1 | Martin | Okay, this went well |
| 2 | Jenny | Let’s do the next |
| 3 | Martin | easy |
| 4 | Martin | That’s simple net force is smaller in B |
| 5 | Jenny | Ok , I check |
| 6 | Martin | One assignment left |
| 7 | Jenny | Instead of 1.5 it says 15 (points to simulation) |
| 8 | Jenny | I must be wrong |
| 9 | Martin | Let’s finish it |
| 10 | Jenny | Next one |

Table 7

*Example episode form the chat-communication of Jonah and Alexander*

| Turn | Student | Chat message |
|---|---|---|
| 1 | Jonah | Oww.. I still don’t get it |
| 2 | Alexander | Like before we have to state some kind of relation |
| 3 | Jonah | I know |
| 4 | Alexander | Look while I pull out the window |
| 5 | Alexander | That way we can have a look at the variables |
| 6 | Jonah | Yeah |
| 7 | Alexander | Ok we have two lists of those |
| 8 | Jonah | No even tree, with the restriction |
| 9 | Jonah | Lets make a list of the variables we can choose |
| 10 | Alexander | I guess |
| 11 | Alexander | We should have an idea or something |
| 12 | Jonah | Yeah |
| 13 | Jonah | Uhum, yes so we have this s |

| | | |
|---|---|---|
| | | variable |
| 14 | Alexander | Do you know what that one is about |
| 15 | Alexander | I remember that Mr. Jones (teacher) talking about it |
| 16 | Jonah | Are we allowed to look it up? |
| 17 | Jonah | Jones will be so pissed if he finds out I forgot about this s thing |
| 18 | Alexander | And now? |
| 19 | Alexander | This really sucks. |
| 20 | Jonah | Well lets look again (starts searching the environment) |
| 21 | Alexander | Heh, I know a stands for acceleration |

Table 8

*Example episode form the chat-communication of Anne and Joseph*

| Turn | Student | Chat message |
|---|---|---|
| 1 | Anne | So we have to state one about distance covered or acceleration |
| 2 | Ester | Yeah, that’s what this level is about |
| 3 | Anne | Well if acceleration is getting larger a car will speed up |
| 4 | Ester | Yes |
| 5 | Anne | Uhum and now… |
| 6 | Ester | We could make acceleration larger, |
| 7 | Anne | So it is speeding up |
| 8 | Ester | Hmm acceleration so if acceleration increases |
| 9 | Ester | The car will drive faster |
| 10 | Anne | Sure |
| 11 | Anne | Reaching the goal sooner |
| 12 | Ester | More meters or kilometers in less time |

| | | |
|---|---|---|
| 13 | Ester | So more distance covered in the same amount of time |
| 14 | Anne | Okay |
| 15 | Anne | Now we have to write it down in the table |

Table 9

*Example episode form the chat-communication of Annetta and Joseph*

| Turn | Student | Chat message |
|---|---|---|
| 1 | Joseph | Okay, I don’t agree I think 1.7 is not true. |
| 2 | Annetta | We can test it with the simulation |
| 3 | Annetta | Look if you have a constant |
| 4 | Annetta | For example 2 meters a second |
| 5 | Joseph | Yeah in that case 2 seconds is 4 meter |
| 6 | Annetta | So it’s twice as large I think |
| 7 | Joseph | Lets run (run the simulation) |
| 8 | Annetta | It seems true |
| 9 | Joseph | Look it is getting steeper. It’s wrong. |
| 10 | Annetta | That’s because you doubled the acceleration |
| 11 | Annetta | If acceleration is zero it is different |
| 12 | Joseph | Ok in that case the car moves at |

| | | |
|---|---|---|
| | | a constant speed. |
| 13 | Annetta | Try it (runs the simulation with new value) |
| 14 | Joseph | Ok, we were right. |
| 15 | Annetta | Try one from level 3 |

Table 10

*Example episode form the chat-communication of William and Sandra*

| Turn | Student | Chat message |
|---|---|---|
| 1 | William | We will do level 3 |
| 2 | Sandra | Ok, I will open it |
| 3 | William | Okay continue and I will think |
| 4 | Sandra | I also need some time to think |
| 5 | William | Is it true that if the mass increases the vehicle moves faster? |
| 6 | Sandra | No, it’s the contrary |
| 7 | Sandra | We can do an experiment on that |
| 8 | William | I will take a look |
| 9 | Sandra | What are you doing |
| 10 | William | I make decrease the mass |
| 11 | Sandra | Save the graph |
| 12 | William | Now with a higher value for mass |
| 13 | Sandra | Save it |
| 14 | William | It is getting slower when mass is high |
| 15 | Sandra | Yeah obvious |

| | | |
|---|---|---|
| 16 | William | Okay we also disagreed on this one |
| 17 | William | Test it |
| 18 | William | Hmm I think that if net force doubles the velocity will double |
| 19 | Sandra | But it has to do with acceleration |
| 20 | Sandra | If a car accelerates it speeds up. |
| 21 | William | Ok we double |
| 22 | Sandra | Ok acceleration doubles and the object is speeding up. |
| 23 | William | Could have told you |
| 24 | Sandra | Test this one (points with mouse) |

Figure Captions

*Figure 1.* Screenshot of a simulation with an assignment

*Scaffolding collaborative inquiry*

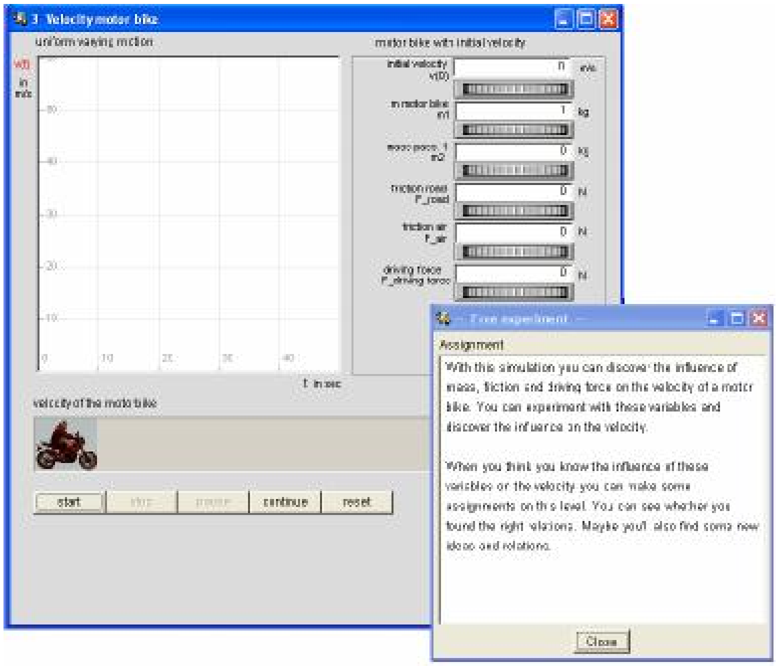
*Figure 2.* Screenshot of the proposition scratchpad with propositions

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

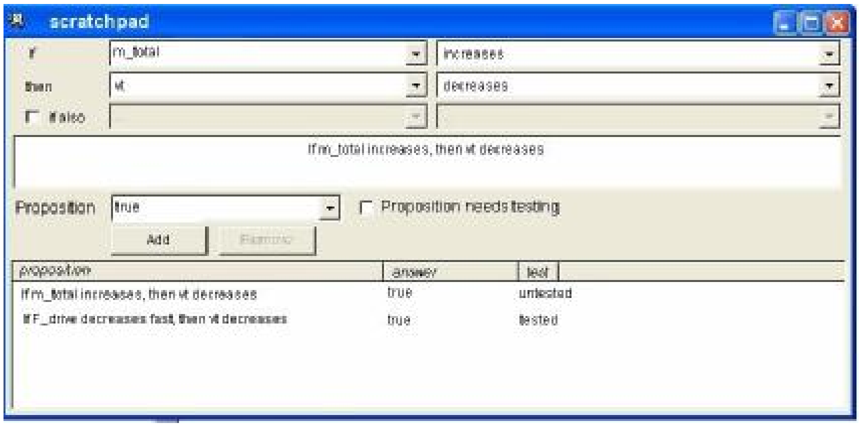
*Figure 4.* Two example items from the definitional domain knowledge test

*Figure 5.* Example item from the “What-if” test

*Figure 6.* Example item from the computerized proposition test



3 Velocity motor bike
uniform varying motion
motor bike with initial velocity
initial velocity v(0)
m motor bike m1
friction road F_road
friction air F_air
driving force F_driving force
t in sec
velocity of the moto bike
start
continue
reset
Free experiment
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.
Close


scratchpad
if
m_total
increases
then
vt
decreases
if also
If m_total increases, then vt decreases
Proposition
true
Proposition needs testing
Add
proposition
answer
test
If m_total increases, then vt decreases
true
untested
If F_drive decreases fast, then vt decreases
true
tested

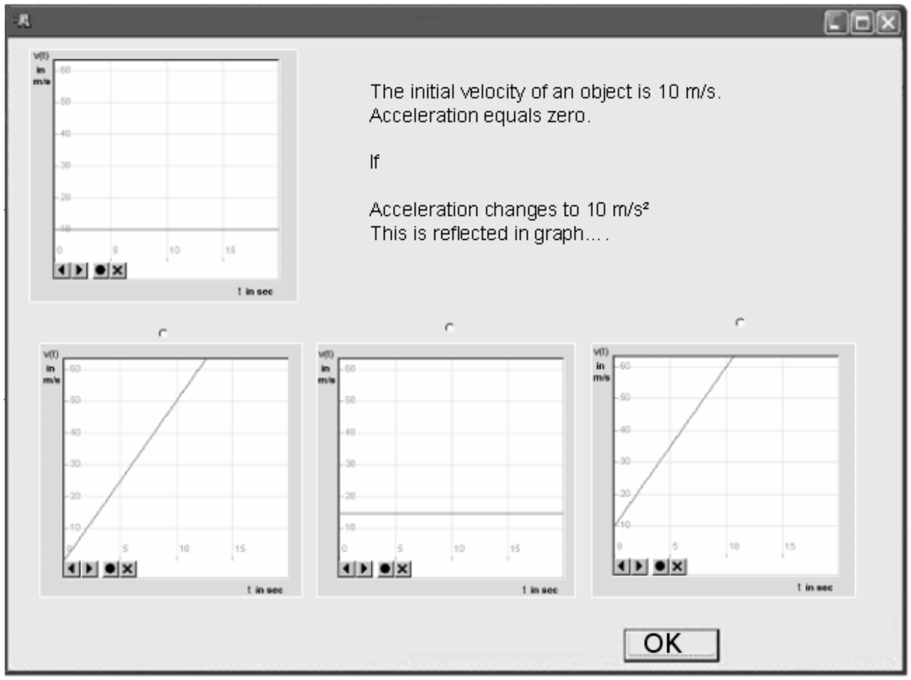

Shared proposition table
proposition
Jonathan
test
Marie-Anne
test
An object with a constant net force will have a constant speed
Probably true
Probably false
If velocity equals zero, acceleration equals zero too
False
False
If the net force of an object doubles, the velocity of this object will also
False
True
Truth-value
Unknown
I want to test this proposition
Experiment
Force & Mass
Simulation

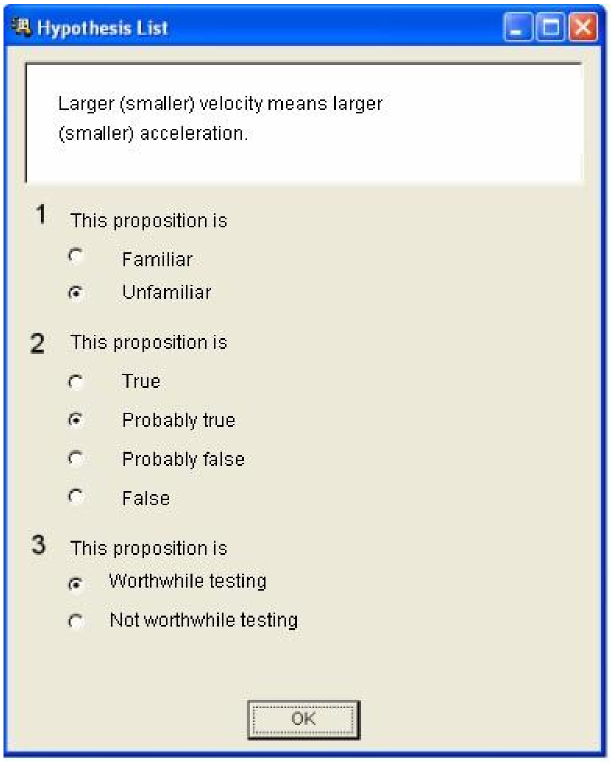
Select the Place-time-function:

A. $s(t) = x_0 + v_0 t + ½at^2$
B. $s(t) = v_0 + a_0 t + ½xt^2$
C. $s(t) = v_0 + x_0 t + ½at^2$
D. $s(t) = x_0 + a_0 t + ½vt^2$

Explain $\frac{\Delta x}{\Delta t}$ in words:

A. Average speed
B. Average acceleration
C. Speed
D. Acceleration


The initial velocity of an object is 10 m/s.
Acceleration equals zero.
If
Acceleration changes to 10 m/s²
This is reflected in graph….
OK


Hypothesis List
Larger (smaller) velocity means larger (smaller) acceleration.
1 This proposition is
Familiar
Unfamiliar
2 This proposition is
True
Probably true
Probably false
False
3 This proposition is
Worthwhile testing
Not worthwhile testing
OK