T. Koschmann, D. Suthers, & T.W. Chan (Eds.), *Computer Supported Collaborative Learning 2005: The Next 10 Years!*
Mahwah, NJ: Lawrence Erlbaum Associates.

Supporting Collaborative Discovery Learning by Presenting a Tool

Nadira Saab
Graduate School of Teaching and Learning
University of Amsterdam
Nadira@ilo.uva.nl

Wouter van Joolingen
Graduate School of Teaching and Learning
University of Amsterdam
Wouter@ilo.uva.nl

Abstract. In collaborative discovery learning students jointly perform experiments to test generated hypotheses with as a result the co-construction of knowledge by means of sharing knowledge and negotiating. In this study, we introduce the Collaborative Hypothesis Tool (CHT), which guided 15 of 25 dyads through the collaborative discovery learning process. The results show that working with the CHT can influence the use of communicative and discovery activities, which can lead to a better learning performance. Future research should be aimed at the stimulation of the use of the tool, since the learners did not use the tool very frequently.

Keywords: Cognitive tools, Collaborative discovery learning, Communication, Discourse analysis,

INTRODUCTION

Collaborative discovery learning combines two constructivist approaches to learning: collaborative learning and discovery learning. In collaborative discovery learning, learners communicate and work together in order to jointly construct knowledge by means of sharing knowledge and negotiating. In discovery learning, by altering the variables and parameters in a simulation and observing the effects, learners can attempt to uncover the rules governing the simulation, and in so doing, build knowledge (De Jong, & Van Joolingen, 1998; Njoo, & De Jong, 1993; Njoo, 1994). The skills and processes employed by learners in discovery learning environments are similar to the skills employed in scientific discovery (Klahr, & Dunbar, 1988; Van Joolingen, & De Jong, 1997). A common distinction in scientific discovery processes is between *regulative* discovery processes, like planning or monitoring, and *transformative* discovery processes, which represent the generation of new knowledge (De Jong, & Njoo, 1992; Njoo, & De Jong, 1993). Scientists' interactions are important in the scientific thinking and reasoning process, because many new ideas arise through externalization of thoughts (Dunbar, 2000). As discovery processes are similar to the scientific processes that scientists use, it can be assumed that successful discovery learning processes can be positively influenced by learning collaboratively (Salomon, & Globerson, 1989). Support for the idea that collaborative discovery learning can be fruitful for the learning process comes from a study carried out by Okada and Simon (1997), where dyads of learners working together were more effective in discovering rules, because they used more explanatory activities compared to learners working individually. In a previous study (Saab, Van Joolingen and Van Hout-Wolters, in press), it was found that communicative activities can contribute to essential stages in a collaborative discovery process. For example, directive and informative activities can contribute to the testing of hypotheses, while argumentation can lead to a successful process of conclusion. This leads to the conjecture that when learners are encouraged to use these communicative activities, a more successful discovery process can be the result.

In the current study, we are interested in supporting the learning processes in collaborative discovery environments. Discovery processes need support (e.g. De Jong & Van Joolingen, 1998), and although in collaborative settings learners can support each other, collaborative discovery learning also needs support. Several studies endorse the view that collaboration without instruction or support on how to collaborate does not automatically lead to a successful learning process or product (Mercer, 1996; Webb & Farivar, 1994). This support can be given as an *instruction*, like the RIDE instruction in a study of Saab, Van Joolingen and Van Hout-Wolters (submitted), or it can be built into the learning environment as *cognitive tools* (Lajoie, 1993; Van Joolingen, 1999).

Cognitive tools are computer technologies that help learners to carry out cognitive tasks. Learners do not learn *from* technologies, but they learn when *working with* technologies, with the technology as a support to the cognitive actions of the learners (Salomon, 1993). According to Lajoie (1993), cognitive tools can serve several functions in assisting learners.

Collaboration can improve learning as shown by several studies (e.g. Van der Linden, Erkens, Schmidt, & Renshaw, 2000; Springer, Stanne, & Donovan, 1999). When working collaboratively, learners externalize their thoughts and become aware of their own ideas and those of their collaborator. By formulating their ideas, possible defects in cognitive of metacognitive processes can become perceptible (Van Boxtel, 2000;

Van der Linden *et al.*, 2000). By internalizing these verbalized thoughts and ideas in an elaborative way (Roelofs, Van der Linden, & Erkens, 1999), by giving elaborative explanations (Webb, 1994) and asking questions (King, 1997), the learning process will succeed more effectively.

Examples of cognitive tools to support discovery learning can be found in the learning environment BioWorld (Lajoie, Lavigne, Guerrera, & Munsie, 2001). BioWorld helps learners with the externalization and evaluation of their reasoning by presenting them with an evidence palette, where evidence is posted in support of the hypothesis generated by the learners, and a belief meter, where the learners can show how comfortable they are with the diagnosis (or hypothesis) stated. The evidence palette is based on the tool that Van Joolingen and De Jong (1991; Van Joolingen, 1993) developed, called the hypothesis scratchpad. The hypothesis scratchpad supports the process of generating hypotheses by presenting elements with which to build hypotheses, like variables and relations.

In our study, we introduce a cognitive tool that can also support collaborative processes between learners. The template offered by the tool should serve as a trigger for collaborative discovery processes. Our cognitive tool, the Collaborative Hypothesis Tool (CHT), is based on the hypothesis scratchpad of Van Joolingen and De Jong (1991; Van Joolingen, 1993). This CHT guides the learners through the processes of collaborative discovery. Moreover, the learners are encouraged to work in a collaborative manner by stimulating them to argue about what hypotheses they should generate and test. In addition, the learners are instructed on how they should test their hypotheses by effectively varying certain variables, and to stimulate them to check if the hypotheses generated are the same as the answer found after doing experiments. We expect that the learners who work with this tool will show more communicative activities that contribute to successful collaboration, and more effective discovery activities, which will lead to better learning results, compared to students who do not use the tool. Our research questions are:

How do the learners use the Collaborative Hypothesis Tool in a collaborative discovery environment?

Does the cognitive tool influence the communicative activities and discovery activities in such a way that the collaborative learning process and the discovery learning process and product improve?

METHOD

Subjects and design

Research participants were 32 dyads of tenth-grade students (15-16 years old) of six secondary schools in Amsterdam who were enrolled in pre-university education with physics as a subject in their examination. The mean age was 15.6 years. The design of the study was a pretest-posttest-control-group-design. The students were randomly divided in an experimental group and a control group. Because of technical reasons (i.e. chat not completely logged or problems with the connection between the two computers) and one chat log with utterances in a language other than Dutch, we had to exclude seven dyads from the data analysis, which resulted in an experimental group containing 15 dyads and a control group containing 10 dyads of students.

Learning environment and task

All students worked together with a learning environment that was based on a computer simulation, "*Collisions*", developed in SIMQUEST (Van Joolingen & De Jong 2003; Saab, et al., in press) [1]. Dyads of students worked collaboratively on two computers with a shared interface, communicating through a chat channel. Students were not familiar with the level "*Collisions*", but were acquainted with the variables presented in the environment.

Before working with the application *Collisions,* by working with a similar environment, also created in SIMQUEST, all learners became familiarized with the learning environment. Additional instructions on collaboration (the RIDE rules (Saab, Van Joolingen, Van Hout-Wolters, submitted)) were also provided. RIDE is based on four general rules, namely Respect, Intelligent collaboration, Deciding together, and Encouraging. The aim of providing this instruction is to have the students communicating more effectively in order to improve the collaborative performance in the learning environment. An earlier study (Saab et al., submitted) showed that instructing these rules can lead to more effective communication.

The learning environment *Collisions*, with which the learners worked after they had received the instruction and practiced with the rules, was different for the experimental group and the control group. The experimental group worked with the same application as the control group, but in addition was presented with

[1] "Collisions" was developed by Hans Kingma and Koen Veermans (Universiteit Twente). SimQuest was developed in the SERVIVE project coordinated by the Universiteit Twente.

a CHT intended to support learners in the generation of hypotheses, planning and concluding. The first process of discovery learning orientation was paid attention to in the assignments, were learners were stimulated to explore the simulation together. This tool consisted of a hypothesis scratchpad, based on a similar tool described in Van Joolingen (1993). In order to use the tool in a collaborative environment, several adaptations were made to it.

Measuring learning outcomes

In this experiment, we identified two types of learning outcome. One is associated with the performance *within* the learning environment; the other is a measure of what is learned *from* this performance. For the latter, the results of a domain knowledge posttest and the gain in score related to the domain knowledge pretest is used as a measure. For the performance within the learning environment, the students could get three points for each assignment. All together, the learners could gain 105 points, divided over 35 assignments (17 open-question assignments and 18 multiple-choice assignments). The multiple-choice assignments were worth 3 points. When the learners gave an argumentation in addition to the plain answer on the open-question assignments, they gained one or two points, depending on the completeness of the answer given. The amount of points gained by a team is taken as a measure of learning results within the learning environment. We label it as SWLE (score within learning environment). The pretest-posttest measure is taken individually, while SWLE is measured on dyads. The domain knowledge pretest and posttest each consisted of two domain knowledge tests, an Explicit Knowledge Test, which tests the learners for declarative knowledge, such as facts and formulas, and a WHAT-IF Test (Swaak, 1998; Veermans, De Jong, & Van Joolingen, 2000). Both tests were developed specifically for the domain of *Collisions*[2] and were administered on-screen. Unfortunately, the reliability of these tests were very low and we did not conduct further analyses.

Procedure

For making up dyads, we chose a heterogeneous group composition (Saab et al, submitted), since research has shown that groups composed of students with differing levels of school grades are more successful working together than are groups made up of students with similar learning results (Blatchford, Kutnick, Baines & Galton, 2003). Participants in the study attended two sessions. In the first session, the participants received individual instruction on collaboration (the RIDE rules). After the instruction, the students practiced collaboratively with an application with logical thinking problems. In this way, the students could practice applying the rules that they had learned earlier in the session. The second session started with the pretest on domain knowledge for all students. Then, they worked together for 90 minutes with the application *Collisions* in the learning environment SIMQUEST, and it ended with the domain knowledge post-tests. The experimental and control groups worked with different versions of the learning environment, as explained in section 'learning environment and task'.

Data collection

All communicative and discovery learning activities were logged and were put together in a single protocol for each dyad. A three-dimensional analysis scheme was used to analyze the protocols. The scheme has been developed and used in previous studies (Saab, et al., in press). The dimensions are: a) communicative activities, b) discovery transformative learning activities, which promote the generation of information (Njoo & De Jong, 1993), and c) discovery regulative learning activities, which support and guide the learning process (Njoo & De Jong, 1993).

In the protocols, each chat utterance, defined as a verbalization typed in a chat window, was scored on the dimensions communicative activities, discovery transformative activities, and discovery regulative activities. Chat utterances were coded on all three dimensions. The SIMQUEST action simulation running was coded only as a discovery transformative activity, collecting data. Two independent raters rated 10% of the protocols, after both raters were trained in using the analysis scheme. Cohen's kappa of inter-rater reliability between the two raters was .94 for the communicative dimension, .89 for the transformative discovery dimension, and .95 for the regulative discovery dimension, which can be considered as good agreement (Fleiss, 1981).

Besides the analyses of the protocols, the use of the Collaborative Hypothesis Tool was investigated for the experimental group. The use of the CHT is measured by the following variables: a) The number of hypotheses generated within the tool with each question where the CHT was presented to the learners, b) The

[2] Both tests were developed by Janine Swaak.

total number of hypotheses generated while using the CHT, c) The proportion of planning activities while using the CHT, d) The proportion of checking if the answer is the same as one of the hypotheses generated while working with the CHT, and e) The proportion correctly answered questions after using the CHT. The frequency of planning and checking if the answer is the same as one of the hypotheses generated while working with the CHT is logged in the answers on the assignments and is, as a consequence, something different than a communicative or discovery activity logged in the protocols.

RESULTS

First, we analyzed the use of the CHT, then we present the differences in learning results between the experimental and the control group, and finally we present the analysis of the learning process.

Collaborative Hypothesis Tool

Relations between the measures of CHT use and activities, including a measure of asymmetry in communication, were tested using Spearman correlation analysis. Asymmetry in communication is the difference in the number of utterances between the participants in one team, presented as a percentage of all utterances of one team. Significant positive correlations were found between the total number of hypotheses generated in CHT and communicative activities all together (r=.58; p<.05). Significant correlations between planning in the CHT and Deciding together activities (r=.53; p<.05), and regulative activities overall (r=.54; p<.05) are found. Significant positive correlations were found between the proportion correctly answered questions after using CHT and Deciding together activities (r=.68; p<.01), transformative activities overall (r=.58; p<.05), and regulative activities overall (r=.61; p<.05).

Learning results

We did not find any significant differences between groups for the performance within the learning environment.

Relation between activities and SWLE for the experimental and control group

To detect which communicative and discovery activities have a positive significant relation with SWLE, we conducted a Spearman correlation analysis between those variables for the experimental and the control groups. We also computed the Fisher's Z' scores to compare the correlation of the experimental and control groups. There are several significant positive correlations in the experimental group: deciding together activities (r=.62; p<.05), transformative activities overall (r=.55; p<.05), and regulative activities overall (r.53; p<.05) correlate significantly with SWLE. No significant correlations are found between SWLE and the frequencies of activities used in the control group. We found significant differences in correlation between the experimental and the control groups, with significantly greater correlation coefficients for the experimental group for deciding together activities (p<.05) and regulative activities overall (p<.05).

Learning process

No significant differences were found in use of frequency of communicative activities or discovery activities between the control and the experimental group.

CONCLUSION AND DISCUSSION

To answer the first research question, we investigated how the collaborating learners used the Collaborative Hypothesis Tool (CHT) and what activities they performed. The learners were free in choosing to use the tool, which, unfortunately, resulted in infrequent use of the tool. This indicates that the learners see no obvious advantage of the collaborative tool. Nevertheless, to see whether the tool contributed to learning in the cases it was used, we conducted correlational analyses. We found that a higher level of communication was related to the number of hypotheses stated on the scratchpad. The planning tool (indicating whether and how a hypothesis should be tested) correlated to communicative activities associated with *Deciding together* as well as with regulation. This indicates that the purpose of the planning indicator served its goal, as it seems to stimulate collaborative decision making and learners' regulation processes. For the assignments for which learners used the CHT, *Deciding together* and regulation were positively correlated with the performance on these assignments. A hypothesis that can be formulated, based on these findings, is that the CHT did induce effective communicative processes for those learners that used it, and that this yielded better performance on the assignments. This is supported by the fact that learners in the control group did not show similar correlations between performance and communicative and learning processes. These differences in correlations are significant (Fisher's Z), which means that using the tool could have effects on the learning results.

We did not find differences in score within the learning environment (SWLE) between the experimental and the control groups, but we did find differences in relations between activities and SWLE for both groups. The activities that have a positive significant relation with SWLE in the experimental group –and notably not in the control group-, are confirmation/acceptance, asking for action (which are both connected to the Deciding together rule which is one of the RIDE rules), and regulative activities overall. The same activities have a significant relation with the amount of correctly answered questions after working with the CHT. This may indicate that these activities, especially communicative activities connected to the Deciding together rule, were used more effectively by the experimental group and, moreover, were effective for using the CHT combined with correctly answered assignments.

The hypothesis that the use of the CHT would have an influence on the use of communicative activities or discovery activities was not confirmed. No significant differences in the use of communicative activities were found between the group that used the CHT and the control group. Communicative activities that were mostly used in both groups were informative, elicitative and confimation/acceptance activities, which is in concordance with Saab et al. (submitted). The experimental group showed a high frequency of use of the same communicative activities. The experimental group is similar to the control group in the present study, because both groups received the RIDE rules instructions under the same conditions.

A likely explanation of the lack of differences between the experimental group and the control group is the little use that was made of the CHT in the experimental group. As noted above, the learners themselves did not see obvious benefit in using the CHT. One cause may be that use of the CHT costs time and resources. Also in a study by Lazonder, Wilhelm, and Ootes (2003) where learners could choose to work with the presented tool or not, most of the time they did not. Apparently, learners are inclined to use a tool only when they see direct benefit or when there is pressure to use it. A possible cause of lack of motivation can be the cognitive overload caused by the many windows that popped up when the CHT was activated. The pop-ups that were presented to the control group (RIDE rules pop-ups) where in consistence with the training both groups received. The CHT was totally new for the experimental group; they did not receive training in how to use the CHT. An idea for future research is to give the learners an opportunity to practice with the tool beforehand so that they will know why they should use it, and how they can use it effectively.

In summary, we found little differences on measures of process and product between the experimental and control groups. However, within the experimental group we did find relations between working with the CHT and process and product of learning. It can be concluded that working with the Collaborative Hypothesis Tool can influence the communicative activities in a way that the collective learning results may improve. Furthermore, the CHT can influence both communicative and transformative discovery activities, with the result that working with the tool leads to more performance of simulations, and performance of simulations is related with giving good answers after working with the tool. Regulative activities seem to be necessary while working collaboratively with the tool with the aim of generating correct answers or it is possible that the tool may evoke the use of regulative activities. In future research, when presenting the CHT to learners, they should be informed about the benefits of the CHT and be trained in the use of the tool before using it in experiments. Discovery learning needs support and so does collaborative learning. Learners who work in a collaborative discovery learning environment should now why and how to work with all features of the environment properly, in order to use the presented tools effectively.

ACKNOWLEDGEMENTS

The scholarship grant provided by Kaleidoscope has given me the opportunity to visit the CSCL2005 conference in Taiwan.

REFERENCES

Blatchford, P., Kutnick, P., Baines, E., & Galton, M. (2003). Toward a social pedagogy of classroom group work. *International Journal of Educational Research,* **39**, 153-172.

Boxtel, C. van (2000). Collaborative concept learning. *Collaborative learning tasks, student interaction, and the learning of physics concepts.* Unpublished doctoral dissertation, University Utrecht.

de Jong, T., & Njoo, M. (1992). Learning and instruction with computer simulations: learning processes involved. In E. de Corte, M. Linn, H. Mandl, & L. Verschaffel (Eds.) *Computer-based learning environments and problem solving.*

Dunbar, K. (2000). What scientific thinking reveals about the nature of cognition. In Crowley, K., Schunn, C.D., & Okada, T. (Eds.) *Designing for Science: Implications from Everyday, Classroom, and Professional Settings.* LEA. Hillsdale:NJ.

Fleiss, J.L. (1981). *Statistical methods for rates and proportions.* NY: John Wiley & Sons.

Jong, T., de & Joolingen, W.R. van (1998). Discovery learning with computer simulations of conceptual domains. *Review of Educational Research,* **68**, 179-201.

Joolingen, W.R. van (1993). Understanding and facilitating discovery learning in computer-based simulation environments. Unpublished doctoral dissertation, Universiteit Twente.

Joolingen, W.R. van, & Jong, T.de (2003). SimQuest, authoring educational simulations. In: T. Murray, S. Blessing, S. Ainsworth: Authoring Tools for Advanced Technology Learning Environments: Toward cost-effective adaptive, interactive, and intelligent educational software. pp. 1-31. Dordrecht: Kluwer.

Joolingen, W.R. van, 1999. Cognitive tools for discovery learning. *International Journal of Artificial Intelligence in Education,* **10**,3-4 (1999), 385-397

Joolingen, W.R., van & Jong, T., de (1991). Characteristics of simulations for instructional settings. *Education & Computing,* **6**, 241-262.

Joolingen, W.R., van & Jong, T., de (1997). An extended dual search space model of learning with computer simulations. *Instructional Science*, **25**, 307-346.

King, A. (1997). ASK to THINK-TEL WHY®©: A model of transactive peer tutoring for scaffolding higher level complex learning. *Educational Psychologist,* **32**, 4, 221-235.

Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science,* **12**, 1-48.

Lajoie, S.P. (1993). Cognitive tools for enhancing learning. In S. P. Lajoie & S.J. Derry (Eds.), *Computers as cognitive tools* (pp. 261-289). Hillsdale, NJ: Erlbaum.

Lajoie, S.P., Lavigne, N.C., Guerrera, C. & Munsie,S. (2001). Constructing knowledge in the context of BioWorld. Instructional Science, **29**, 2, pp.155-186.

Lazonder, A.W., Wilhelm, P., & Ootes, S.A.W. (2003). Using sentence openers to foster student interaction in computer-mediated learning environments. *Computers & Education,* **41,** 3, 291-308.

Linden, J. van der, Erkens, G., Schmidt & H., Renshaw, P. (2000). Collaborative Learning. *In P.R.J. Simons, J. van der Linden and T. Duffy (Eds.), New Learning*. Dordrecht: Kluwer Academic Publishers.

Mercer, N. (1996). The quality of talk in children's collaborative activity in the classroom. *Learning and Instruction,* **6,** 4, 359-377.

Njoo, M.K.H. (1994). *Exploratory learning with a computer simulation: learning processes and instructional support*. Eindhoven: Technische Universiteit Eindhoven.

Njoo, M.K.H., & Jong, T., de (1993). Exploratory Learning with a Computer Simulation for Control Theory: Learning Processes and Instructional Support. *Journal of Research in Science Teaching,* **30**, 8, 821-844.

Okada, T, & Simon, H.A. (1997). Collaborative Discovery in a Scientific Domain. *Cognitive Science*, **21**, 2, 109-146.

Roelofs, E., Linden, J., van der & Erkens, G. (1999). Leren in dialoog. Een discussie over samenwerkend leren in onderwijs en opleiding. *Pedagogische Studiën,* **76**, 6, 7-34.

Saab, Joolingen, van , W.R., & Hout-Wolters, van B.H.A.M. (in press). Communication in collaborative discovery learning. *British Journal of Educational Psychology*.

Saab, Joolingen, van , W.R., & Hout-Wolters, van B.H.A.M. (submitted). Supporting communication in a collaborative discovery learning environment.

Salomon, G. (1993). On the Nature of pedagogic computer tools: The case of the writing partner. In S. P. Lajoie & S.J. Derry (Eds.), *Computers as cognitive tools* (pp. 179-196). Hillsdale, NJ: Erlbaum.

Salomon, G., & Globerson, T. (1989). When teams do not function the way they ought to. *International Journal of Educational Research*, **13**, 89-98.

Springer, L., Stanne, M.E., Donovan, S.S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology. A meta-analysis. *Review of Educational Research,* **69**, 21-51

Swaak (1998). *What-if, discovery simulations and assessment of intuitive knowledge.* Doctoral dissertation, University Twente.

Veermans, K.H., Jong, T, de, & Joolingen, W.R., van (2000). Promoting self directed learning in simulation based discovery learning environments through intelligent support. *Interactive Learning Environments,* **8**, 229-255.

Webb, N.M. & Farivar, S. (1994). Promoting helping behavior in cooperative small groups in middle school mathematics. *American Educational Research Journal*, **31**, 2, 369-395.

Wegerif, R. (1996). Using computers to help coach exploratory talk across the curriculum. *Computers and Education,* **26**, 1-3, 51-60.