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Supporting Communication in a Collaborative Discovery Learning Environment: the Effect of Instruction

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Abstract. We present a study on the effect of instruction on collaboration in a collaborative discovery learning environment. The instruction we used, called RIDE, is built upon four principles identified in the literature on collaborative processes: *Respect, Intelligent collaboration, Deciding together*, and *Encouraging*. In an experimental study, a group of learners (ages 15–17) receiving this instruction was compared to a control group. The learners worked in dyads on separate computers in a shared discovery learning environment in the physics domain of collisions, communicating through a chat channel. Qualitative and quantitative analyses of the logged actions in the learning environment and the chat protocols showed that the RIDE instruction can lead to more constructive communication, and improved discovery learning activities, as expected, although no direct effect on discovery learning results was found. This study shows the benefits of providing instruction on effective communication and the learning process in a collaborative discovery learning situation.

Keywords: CMC, collaborative discovery learning, computer-mediated communication, teaching/learning strategies, interactive learning environments, simulations, instruction

Introduction

Research has shown that collaboration between learners may improve learning (e.g. Springer et al., 1999; van der Linden et al., 2000). In a collaborative learning situation, two or more learners working together, for example, to solve a problem or create a product for an assignment, constructing knowledge through communication and the shared use of tools and representations. Collaboration requires learners to externalize their reasoning by means of communication, which may make them aware of possible deficits in their thinking (van Boxtel, 2000; van der Linden et al., 2000). When they then internalize their thoughts in an elaborative way (asking questions and giving explanations) (Marshall, 1995; Roelofs et al., 1999), this can lead to a better organization of existing knowledge or the constructing of new knowledge (Wegerif, 1996; Chan et al., 1997; Wegerif & Mercer, 1997). Collaborative learning can contribute to better learning in problem solving situations (e.g. Mercer, 1996), as well as in discovery learning environments (Salomon & Globerson, 1989; Saab et al., 2005). Collaboration triggers learners to elaborate their thoughts as part of the communication (Dekker & Elshout-Mohr, 1998). Learners, working in a collaborative environment can make the discovery learning processes explicit, which can lead to a positive contribution to these processes. Okada & Simon (1997) showed in their research that collaborative learning enhanced discovery learning, because, for instance, generating hypotheses was made explicit by the participants, which resulted in a better performance compared to the learners who worked individually. In the current article, we focus on computer-based learning environments where learners are collaboratively involved in the discovery learning process by means of chatting with each other. Among the advantages of using chat as opposed to face-to-face communication is the possibility for learners to see the history of their communication so that the discussion becomes explicit (Veerman et al., 2000), and that they need to explicitly formulate their thoughts before sending a message.

It is not self-evident that learners know how to collaborate constructively. Several studies have shown that collaboration without instruction or support on how to collaborate does not lead automatically to effective knowledge construction (Webb & Farivar, 1994; Ross & Cousins, 1995; Mercer, 1996; Chan, 2001). For example, some learners in a team can do all the work while the other participants do little or even nothing, the so-called free-rider effect (Wasson, 1998). Another example is that learners work individually (Ettekoven, 1997) and do not check with their partners if everything is understood (Baker et al., 1999). In a previous study (Saab et al., 2005), we found a relation between the communication process of argumentation and the discovery process of drawing conclusions. Directive and informative communication processes and the discovery processes of orientation and hypothesis generation were also related in this study. Based on the findings of our research, we can hypothesize that if it were possible to induce these communicative processes in learners, a more successful discovery process may be achieved.

Although it may be fruitful to support learning by means of collaborative learning, collaboration itself may need support. Such support can be offered in different ways. It can be built into the learning environment as *cognitive tools* (Lajoie, 1993; van Joolingen, 1999) or it can be presented as an *instruction* that is given before or during the interaction with the learning environment. An example of a cognitive tool that may be provided to the learner to support communication is sentence openers; a pull-down menu or buttons, with pre-specified beginnings of an expression that can be used to start an utterance. Research on this kind of tool has led to different results. In some studies the use of sentence openers led to more argumentative talk (e.g. Baker & Lund, 1997), whereas Lazonder et al. (2003) found that learners given the choice to use the tool, did not use it frequently.

The other method of supporting the collaborative learning process is providing learners with instructions on how to collaborate. Where learners do not know what is expected, or where they work individually instead of collaborating (Ettekoven, 1997) instruction on how to behave effectively in collaborative settings may have a positive effect on the collaborative processes (Mercer, 1996).

Mercer and colleagues conducted several experiments where they gave instructions in effective communication to children between ages 8- and 11-year-old (e.g. Mercer, 1996; Wegerif et al., 1999; Rojas-Drummond & Mercer, 2003). They found an increase of exploratory talk after the children received instructions. Exploratory talk is a kind of discussion where learners talk through their problems and investigate ideas together. It may be characterized by giving statements and new ideas, and reacting constructively and critically on these statements by offering justifications and alternative hypotheses. They also found that exploratory talk leads to better problem solving, both for a group and for the individual. The instructions that elicited explorative talk were based on ground rules (Mercer, 1996; Wegerif et al., 1999). These rules included, for example, that the groups have to seek agreement; that alternative ideas have to be discussed before the groups reach agreement; and that the participants ask for reasons when appropriate.

A basic question is what the contents of such instruction should be. To give effective instruction in collaboration, we need to know the important communicative activities for effective collaboration. In the literature, several characteristics of effective collaboration are mentioned:

- Learners should allow all participants to have a chance to join the communication process (Wegerif & Mercer, 1996);
- Learners should share relevant information and consider ideas brought up by every participant thoroughly (King, 1997; Wegerif et al., 1999);

- Learners should provide each other with elaborated help and explanations (Webb & Farivar, 1994; Wegerif, 1996; King, 1997; Ploetzner et al., 1999; She, 1999; Weiss, & Dillenbourg, 1999);
- Learners should strive for joint agreement by, for example, asking verification questions (Mercer, 1996; Wegerif & Mercer, 1996; Baker et al., 1999; Wegerif et al., 1999; van Boxtel et al, 2000);
- Learners should discuss alternatives before a group decision is taken or action is undertaken (cf. Wegerif et al., 1999; Veerman et al., 2000);
- All learners should take responsibility for the decisions and action taken (Ebbens et al., 1997; Wegerif, et al., 1999);
- Learners should ask each other clear and elaborated questions until help is given (Chi et al., 1989; Webb & Farivar, 1994; Wegerif & Mercer, 1996; King, 1997; Wegerif et al., 1999; Veerman et al., 2000);
- Learners should encourage each other (King, 1997);
- Learners should provide each other with evaluative feedback (King, 1997).

These characteristics are found in several studies on how to support or instruct effective communication. However, none of them was aiming to support synchronous distance communication, such as text-based chat. For our study, we developed a computerized instructional program to assist learners to collaborate by means of chat. The content of the instructional program was based on our findings in the literature described above. The rules we extracted were grouped under four principles: *Respect, Intelligent collaboration, Deciding together*, and *Encouraging*, which we labeled as the "RIDE rules". Every rule had a number of sub-rules. The *Respect* rule included the sub-rules 'everyone will have a chance to talk', and 'everyone's ideas will be thoroughly considered'. The *Intelligent collaboration* rule included: 'sharing all relevant information and suggestions', 'clarify the information given', explain the answers given', and 'give criticisms'. The sub-rules of the *Deciding together* rule are: 'explicit and joint agreement will precede decisions and actions', and 'accepting that the group (rather than an individual member) is responsible for decisions and actions'. Finally, the *Encouraging* rule includes: 'ask for explanations', 'ask until you understand', and give positive feedback' as sub-rules.

The form of instruction was based on the principles of the cognitive apprenticeship model or situated cognition (Hendricks, 2001; de Jager et al., 2002; Masterman & Sharples, 2002): activating prior knowledge of the learners, modeling of skills, coaching or supporting, scaffolding, articulation by the learners, and evaluation and reflection by the learners (Webb & Farivar, 1994). The detailed design of the instructional program is described in the Method section below.

We expect that instruction based on the RIDE rules will lead to more communicative activities that contribute to successful collaboration. The study presented here investigates the effects of this instructional program. It is expected that the instruction will lead to an increase in relevant communication activities, as summarized under the RIDE rules. Based on the results of our previous study (Saab et al., 2005), we hypothesize that this will in turn lead to more effective discovery learning activities, in particular for the *Intelligent Collaboration* part of the RIDE rules, as this category encompasses argumentation and informative activities for which a positive effect was found. Hence, the research questions are: *Can instruction in effective communication in a discovery learning environment lead to*:

- more effective communicative activities during the discovery learning process?
- more effective discovery learning activities?
- improved discovery learning results?

Method

Subjects and design

This study involved 38 pairs of tenth-grade students of a secondary school who were following pre-university education, and who had chosen physics as a topic. Their age ranged from 15 to 17 years. The learners were recruited from three secondary schools in Amsterdam. For their participation, subjects received €20. The design of the study was a pretest–posttest control group design. The learners were randomly assigned to an experimental group and a control group. Due to technical problems and the fact that some learners did not show up in the second session nine pairs dropped out. As a result, the experimental group contained 17 and the control group 12 pairs of learners.

Learning environment and task

The learners worked together with a learning environment that was based on a computer simulation, *Collisions*, developed in SimQuest (van Joolingen & de Jong, 2003)[1]. The main learning task was to discover the rules of physics behind the simulation. In *Collisions*, learners were presented with assignments that focused their attention to a specific part of the model they investigated. Assignments presented the learners with a small research question. Some assignments presented learners with a multiple-choice question, others presented an open question, where learners were supposed to type in an answer. Data for answering the assignments could be collected using the simulation. The environment also contains explanations for each of the variables present in the simulation. These explanations are available on request by the learners. Pairs of learners worked collaboratively on two computers with a shared interface, communicating through a chat channel (Figure 1). Pairs were distributed over two separate rooms to avoid direct face to face communication.

The learning environment was different for the experimental group and the control group. Whenever an assignment is opened in the experimental version, a prompt (Wegerif, 1996) will pop up reminding the learners of one of the rules of the instructional program (i.e. the RIDE rules). An example of such a prompt is given in Figure 2. The control group did not receive any kind of pop-ups.

Before working with the application *Collisions*, learners in both groups received an instructional program. The goal was to acquaint them with the learning environment by working with a similar environment (both SIMQUEST). The control group received an instructional program on logical reasoning problems, which had nothing to

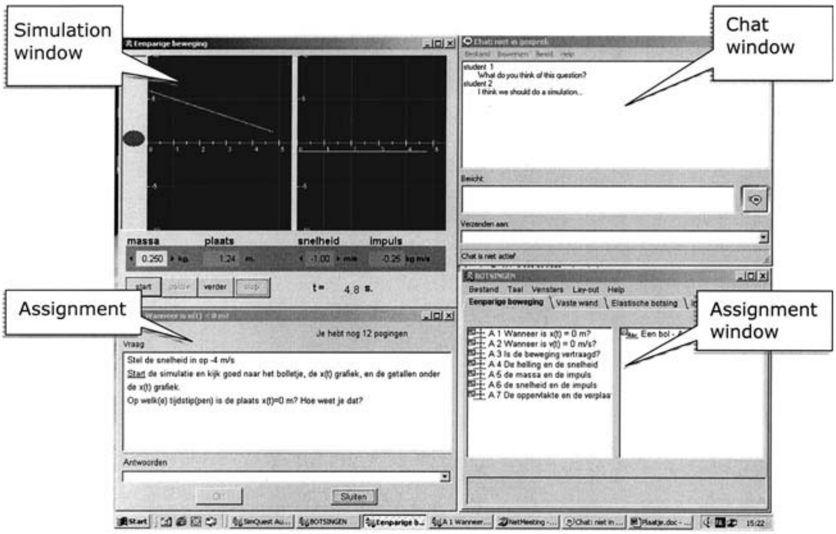

Figure 1. Screenshot of the learning environment used. Shown are the simulation window, assignment windows and chat window.

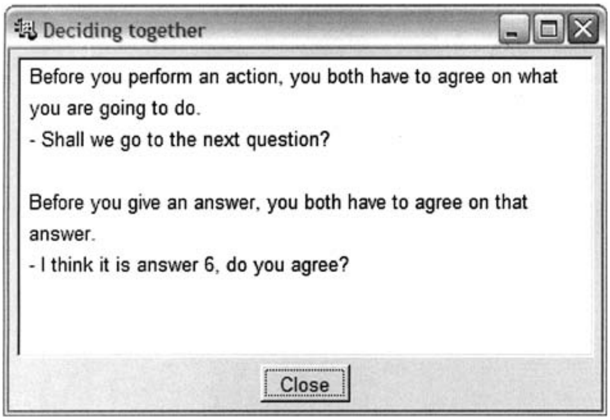

Figure 2. Example of a prompt with the rule *Deciding together* with sub-rules (translated from Dutch).

do with the experiment, and the experimental group received an instructional program on collaboration, i.e. the RIDE instructional program.

The instructional program with the RIDE rules consisted of a recorded computerized presentation, where the rules were explained by both audio and visual means. After the presentation, the learners practiced the rules by working together in the SimQuest environment, where they were reminded by means of prompts to follow the rules while collaborating. The goal of this instructional program with the RIDE rules was that the learners also would pursue the rules later on, when participating in the real experiment (working with the application *Collisions*).

The computerized instruction was designed as follows: First, the learners received an introduction of the rules on screen where they could read each rule and where at the same time the rule was being read aloud by a voice recorded in the computer. Second, the four main rules (RIDE) were clarified by showing the sub-rules of each main rule. The learners could read the sub-rules with every general rule. Furthermore, an example of every sub-rule was being read out loud. Third, several chats with good and bad examples of the use of every rule were shown. Every example started with the announcement of the rule read out loud, then an assignment was shown, followed by the communication process of two people that are solving a problem together showed in an chat window. The learner is then stimulated by a question (audio) to consider whether the communication between the people in the chat window is good or bad. Finally, the example was being evaluated (audio). The instructional program on screen was repeated for each of the four RIDE rules. After receiving the instructional program on screen, the learners could practice together with a SimQuest application while communicating through chat. In the application, they received two different kind of assignments, namely assignments about the RIDE rules where the learners were asked to think about when and how to use them, and logical reasoning problems, where they could practice using the rules while solving problems together. Finally, after practicing with the logical reasoning application, the learners had to fill in together (on screen) an evaluation form. They were asked whether the rules were applied in the practice session, where they think they had to pay attention to in the future, how the collaboration went, and if they liked it. The data of the evaluation forms were collected and showed that 83% of the learners mentioned they applied the rules with ease. The learners found that the following aspects of the rules went well: explaining, asking for opinions or explanations, making decisions together and respecting each other (for example: listening to each other), although explaining was sometimes found difficult.

Measuring learning performance

In this experiment, we identified two types of learning performance. One is associated with the performance *within* the learning environment; the other is a measure of what is learned *from* this performance, i.e. the learning outcome. For the latter, the results of a domain knowledge pretest and the gain in score related to the domain knowledge pretest were used as a measure. For the performance within the learning environment, the learners could get three points for each assignment. With some of the assignments the learners could earn more than one point (with a maximum of three points) when they gave an argumentation in addition to the plain answer. All together, the learners could gain 105 points, divided over 35 assignments. This measure, which we call SWLE (score within learning environment) is a team score, not one of individuals as opposed to the pretest–posttest measure.

The domain knowledge pretests and posttests 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 et al., 2000), which asks the learners to predict an effect of a change after showing them situations before a collision, and presenting a change in the situation.

Both tests[2] were developed specifically for the domain of *Collisions* and were administered on screen. The pretests and posttests were both parallel versions of the tests. In earlier experiments (Saab et al., 2005), learners could not finish all the levels of the *Collisions* application in the time given. That is why the last of the four levels in the application were removed as well as the corresponding items in the pre- and post-tests. The explicit knowledge test consisted of 15 items (originally 20 items) and the WHAT-IF test consisted of 13 items (originally 24).

Procedure

For making up dyads, we chose a group composition that is heterogeneous with respect to school achievement, since research has shown that learners working in such groups are more successful working together than learners working in homogeneous groups (Blatchford, et al., 2003). The reason is that the brighter learner can learn from giving elaborated explanations (Webb & Farivar, 1994), while the weaker learner can learn from the explanation given (van der Linden et al., 2000). However, the difference in level between learners should not be too large. We used the grades of the learners, provided by the teachers beforehand, to identify the levels of achievement of the learners. To compose heterogeneous groups we used a method based on the one Pijls et al. (2003) used in their study. All learners received a token: a colored triangle or circle. The color stood for grade (red was either high or low graded, yellow was middle grade), and the shape stood for condition. Subjects were not informed about this meaning. Subjects were free to choose a partner who had a token with the same shape but different color. This assured that the dyads were composed of either a low and a middle graded learner or a middle and a high graded learner, and that learners could choose someone that they liked to work with.

Participants in the study attended two sessions. In the first session, the participants in the experimental group received individual an instructional program on collaboration according to the RIDE rules. In the first session, the control group received an instructional program on how to solve logical reasoning problems, which has nothing to do with the content of the experiment. This session dealt with problems such as: "Tomorrow it is Wednesday. What day is it four days before yesterday?" After the instruction sessions, all learners practiced with the simulation learning environment SimQuest on an application with logical reasoning problems, in a collaborative setting similar to the *Colli-*

sion environment. The answers given during this session were not used in the analyses of this study. In this way, the learners from both groups became acquainted with working together in this learning environment. Furthermore, the learners in the experimental group could practice applying the rules they had learned earlier in the session.

The second session started with the pre-domain knowledge tests for all learners. Then, they worked together for a fixed time of 90 min with the application *Collisions* in the learning environment SimQuest, and it ended with the post-domain knowledge tests.

Data collection

All communicative and discovery learning activities were logged, as well as the chats, and were put together in a single protocol for each dyad. We coded each activity on three different aspects, namely: (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) (see Table 1). The communicative part of the analysis scheme is partly based on the analysis scheme that van Boxtel (2000) used in her study of collaborative concept learning. The scheme has been developed and used before in a descriptive study about the frequency of communicative activities used in the discovery learning process and the co-occurrence of communicative and discovery activities (Saab et al., 2005). A chat utterance is defined as a verbalization typed in the chat window (Lebie et al., 1996). Two independent raters rated 10% of the protocols, after both raters were trained in using the analysis scheme. Both raters were blind to the conditions. Cohen's Kappa of inter-rater reliability between the two raters was $\kappa = 0.89$ for communicative activities, $\kappa = 0.83$ for transformative discovery activities, and $\kappa = 0.97$ for regulative discovery activities, which can be considered as good agreement (Fleiss, 1981).

The analysis scheme for communicative actions is quite generic. In order to see the specific effects of the RIDE instruction, we need to zoom in on a subset of the communicative activities, namely those communicative actions that represent the activities that are promoted in RIDE. As mentioned in the introduction, instruction in the RIDE rules can lead to specific communicative activities. Table 2 shows the RIDE rules and the communicative activities we expect will be elicited by these rules. *Respect* for each other (R) is represented by an even

Table 1. Analysis scheme used to analyze student's actions and interactions on utterance level

Communicative activities	Discovery transformative activities	Discovery regulative activities
Informative	Orientation	Orientation
Argumentative	Identification of parameters and variables	Planning
Evaluative	Collecting data	Evaluation
Negative	Interpreting data and graphics	Monitoring
Positive		
Elicitative (Asking:)	Generating hypothesis	
For Understanding	Describing and recognizing of relations	
For Agreement	Thinking of alternative answers	
Open questions	Proposing an answer	
Critical questions	Formulating hypotheses	
After incomprehension	Thinking of alternative hypotheses	
For action		
Responsive	Hypothesis testing	
Informative	Experimental design	
Confirmation/Acceptance	Predicting	
Negative	Collecting data	
Directive		
Off task		
Technical	Conclusion	
Coordinated	Interpreting data and graphics	
Social talk	Rejecting hypotheses	
	Concluding	
	No discovery transformative activity	
		No discovery regulative activity

amount of utterances in teams, and little negative individual evaluation. *Intelligent collaboration* (I) is represented by informative responses, asking for understanding, argumentative, and informative activities. *Deciding together* (D) is represented by asking for action, confirmation/acceptance, asking for agreement, and coordinated off task talk. *Encouraging* (E) should lead to an increased occurrence of asking open questions, asking critical questions, asking after incomprehension, and positive individual evaluation.

Table 2. Communicative sub- and main activities that represent application of the RIDE rules

RIDE Rules	Communicative activities
(R) Respect	• Less negative individual evaluation (Evaluative)
	• More symmetry in communication
(I) Intelligent collaboration	• Informative responses (Responsive)
	• Asking for understanding (Elicitative)
	• Argumentative activities
	• Informative activities
(D) Deciding together	• Asking for action (Elicitative)
	• Confirmation/acceptance (Responsive)
	• Asking for agreement (Elicitative)
	• Coordinated off task talk (Off task)
(E) Encouraging	• Asking open questions (Elicitative)
	• Asking critical questions (Elicitative)
	• Asking after incomprehension (Elicitative)
	• Positive individual evaluation (Evaluative)

Results

Communicative activities

To investigate whether the instructional program leads to more effective communicative activities, we compared the frequencies of communicative activities between the experimental and control group, using a Mann–Whitney *U*-test with one-tailed testing to see possible significant differences between the two groups. We chose the Mann–Whitney *U*-test, because of the skewness and the broad distribution of some of the variables. We used absolute frequencies as the time the learners worked with the application was equal for the experimental and the control group.

From Table 3, we see that four groups of communicative activities are significantly more frequently used in the experimental group than in the control group: elicitative, responsive, confirmative/acceptance activities, and asking for action.

We conducted a Mann–Whitney *U*-test with one-tailed testing to detect possible differences in frequencies of the RIDE rules activities between the experimental and the control group. As the *Respect* rule is represented by components that are not expressed in frequency of activities they are therefore not used in the analysis. For this rule, the

Table 3. Absolute frequencies of communication activities and the results of a Mann–Whitney *U*-test for differences

Activities	Frequencies experimental group		Frequencies control group		Mann–Whitney *U*		
Communication	Mean	SD	Mean	SD	*U*	*z*	p^a
Informative	35.00	16.59	28.25	18.22	76.0	1.152	0.132
Argumentative	24.76	13.82	17.33	10.55	66.5	1.574	0.059
Evaluation	9.24	5.87	8.33	10.12	75.5	1.177	0.123
Elicitative	37.29	15.28	27.83	14.59	58.5	1.927	0.027*
Responsive	37.18	14.60	26.75	13.79	53.0	2.174	0.015*
Confirmation/acceptance	34.59	13.79	25.00	20.40	54.0	2.127	0.017*
Negative response	4.24	2.95	4.25	3.25	98.0	0.179	0.440
Directive	10.59	7.92	10.58	5.60	89.5	0.556	0.293
Asking for action	16.12	10.22	8.58	7.08	54.5	2.108	0.017*
Off task							
Technical	10.88	9.78	9.58	8.22	95.0	0.312	0.389
Coordinated	14.06	8.39	15.75	19.01	89.0	0.577	0.293
Social talk	43.35	27.85	48.08	26.85	86.0	0.709	0.250
Total	262.47	81.54	217.42	104.73	67.0	1.550	0.064

*$p < 0.05$.
[a]One-tailed significance.

measures on the components are given. Asymmetry in communication is the difference in amount of utterances between the participants in one team, presented as a percentage of all utterances. Table 4 shows that the communicative activities elicited by the rules *Deciding together* and *Encouraging* were used significantly more often in the experimental group.

Discovery activities

Table 5 shows the frequency of the discovery learning activities (transformative and regulative) and the results of a Mann–Whitney *U*-test between the experimental group and the control group. The transformative activities describing and recognizing of relations, and concluding were used significantly more often by the experimental group than by the control group. Compared to the control group, the experimental group made significantly more use of the regulative activity evaluation and regulation overall.

Table 4. Absolute frequencies of RIDE related communicative activities and the results of a Mann–Whitney *U*-test for differences

RIDE Rules	Experimental group		Control group		Mann–Whitney *U*		
	Mean	SD	Mean	SD	*U*	*z*	p^a
(R) Respect for each other							
Negative individual evaluation	0.59	0.94	1.58	2.43	80.5	1.069	0.174
Asymmetry in communication (in percentages)	7.75	5.36	10.28	6.24	76.5	1.129	0.132
(I) Intelligent collaboration	69.12	32.29	52.17	29.84	72.5	1.307	0.098
(D) Deciding together	79.94	26.20	62.08	49.09	49.0	2.349	0.009**
(E) Encouraging	24.88	11.34	15.25	10.98	48.5	2.374	0.008**

$^{**}p < 0.01$.
[a]One-tailed significance.

Instruction and discovery activities

Table 6 shows the significant Spearman correlations that were found between the frequencies of the communicative activities associated with the *Intelligent collaboration*, the *Deciding together*, and the *Encouraging* rule (see Table 2) and the discovery learning activities for the experimental and the control group. Due to the reasons given in earlier in this section, such analysis is not possible for the *Respect* rule. The communicative activities coupled to the (R)IDE rules correlate with several discovery learning activities in both the experimental and control group, especially the rule *Intelligent collaboration*. The discovery regulative learning activities monitoring and planning have significant correlations with all the three rules.

Learning results within the learning environment, related to activities

A one-way between-groups analysis of variance was conducted to detect differences in group scores within learning environment (SWLE) and number of assignments completed between the experimental group and the control group (Table 7). We did not find any significant differences between groups.

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

Table 5. Absolute frequencies of discovery learning activities and the results of a Mann–Whitney *U*-test for differences

Activities	Frequencies experimental group		Frequencies control group		Mann–Whitney *U*		
	Mean	SD	Mean	SD	*U*	*z*	p^a
Discovery transformative learning							
Orientation							
Identifying parameters and variables	1.12	1.05	0.92	1.24	87.5	0.680	0.264
Collecting data	17.82	8.22	14.58	5.50	83.5	0.821	0.210
Interpreting data and graphics	2.65	3.43	1.33	2.60	70.5	1.506	0.083
Hypothesis generating							
Describing and recognizing of relations	7.00	5.29	3.08	2.64	54.0	2.138	0.017*
Thinking of alternative answers	2.18	2.92	1.83	1.95	102.0	0.000	0.500
Proposing an answer	5.12	3.12	4.75	3.86	84.0	0.806	0.222
Formulating hypotheses	21.53	10.78	15.50	6.71	73.0	1.286	0.106
Thinking of alternative hypotheses	3.00	3.04	3.67	2.39	84.5	0.787	0.222

Hypothesis testing							
Experimental design	8.76	8.33	6.92	7.43	84.5	0.779	0.222
Predicting	0.65	0.86	0.25	0.87	72.0	1.691	0.098
Collecting data	20.88	11.73	22.58	12.00	91.5	0.466	0.324
Conclusion							
Interpreting data and graphics	4.12	3.59	3.67	6.02	70.5	1.418	0.083
Rejecting hypotheses	0.82	1.29	2.25	2.49	70.5	1.489	0.083
Concluding	9.71	6.29	6.25	6.92	58.5	1.933	0.027*
Total	105.35	35.25	87.58	35.04	72.0	1.329	0.098
Discovery regulative learning							
Orientation	3.88	3.257	3.25	3.36	91.0	0.492	0.324
Monitoring	50.41	24.64	38.58	26.92	71.0	1.373	0.090
Planning	22.29	10.45	15.83	11.09	66.0	1.596	0.059
Evaluation	4.94	3.54	3.58	5.28	60.5	1.871	0.033*
Total	81.53	31.20	61.25	39.77	60.0	1.860	0.033*

*$p < 0.05$.
[a]One-tailed significance.

Table 6. Significant Spearman correlations between the frequencies of RIDE rule communicative and discovery learning activities for the experimental and the control group

Activities	Intelligent collaboration		Deciding together		Encouraging	
	E[a]	C[b]	E[a]	C[b]	E[a]	C[b]
Discovery transformative learning						
Orientation						
Identifying parameters and variables						
Collecting data	0.534*	0.581*				
Interpreting data and graphics						
Hypothesis generating						
Describing and recognizing of relations						
Thinking of alternative answers		0.901**				
Proposing an answer	0.780**	0.608*				
Formulating hypotheses	0.757**	0.708*				
Thinking of alternative hypotheses	0.661*		0.662*	0.604*		
Hypothesis testing						
Experimental design			0.504*			0.859**
Predicting				0.607*		
Collecting data	0.496*					
Conclusion						
Interpreting data and graphics	0.545*	0.734**				
Rejecting hypotheses		0.682*				
Concluding	0.854**	0.655*	0.485*			
Total						
Discovery regulative learning						
Orientation						
Monitoring	0.523*		0.546*		0.583*	0.695*
Planning	0.542*	0.742**	0.634**	0.578*	0.523*	
Evaluation						
Total						

*$p < 0.05$. **$p < 0.01$.
[a]Experimental group.
[b]Control group.
Note: Only significant correlations are shown.

Table 7. Anova on SWLE and amount of questions answered between the experimental group and the control group

	Experimental group		Control group		F	df	p
	Mean	SD	Mean	SD			
SWLE	27.59	10.28	29.33	14.60	0.142	1.27	0.709
Number of assignments completed	16.82	5.42	18.17	5.08	0.454	1.27	0.506

the control group. We also computed Fisher's *Z*s scores to compare the correlation of the experimental and control groups. The results are shown in Table 8. In the experimental group there are some significant positive correlations: informative communication, proposing an answer, formulating hypotheses, and collecting data correlate significantly with SWLE. A significant negative correlation is found between SWLE and offtask technical talk in the control group. There are no significant correlations between the frequencies of activities used and SWLE in the control group. In the control group, we found a significant correlation ($r = 0.61$) between the asymmetry of communication and SWLE. We found a significant difference in correlation between the experimental and the control group for formulating hypotheses.

Learning results on domain knowledge

For technical reasons (i.e. not everything was completely logged), the scores of six participants were not included in the analyses of the pre- and post-domain knowledge tests. The reliability of the pre- and post-domain knowledge tests was considerably low. Using a covariance analysis with the pretests as a covariate, no significant differences were found between groups.

Conclusion and discussion

In this article we present an attempt to support communicative processes in a collaborative discovery learning environment by introducing an instructional program before and, represented by prompts, during the learning process. The hypothesis was that this instructional program would lead to more effective communication processes which, in turn, would lead to more productive discovery processes

Table 8. Correlations between frequencies of communicative and discovery activities and learning results within the learning environment (SWLE) for both experimental and control group, as well as a Fisher's *z*-test on the differences between these correlations

	SWLE			
Communicative activities	Experimental group	Control group	Z^a	*p*
Informative	0.51*	−0.23	1.87	0.06
Argumentative	0.31	−0.16	1.13	0.26
Evaluation	0.38	0.34	0.11	0.91
Elicitative	−0.02	−0.13	−0.17	0.87
Responsive	−0.12	0.00	−0.28	0.78
Confirmation/acceptance	0.13	0.15	−0.05	0.96
Negative response	0.36	0.03	0.81	0.42
Directive	−0.02	−0.47	1.15	0.25
Asking for action	0.08	0.26	−0.44	0.66
Off task				
Technical	−0.61**	0.08	−0.185	0.06
Coordinated	0.11	0.04	0.16	0.87
Social talk	0.36	0.33	0.08	0.94
Total	0.28	0.07	0.51	0.61
Discovery transformative learning				
Orientation				
Identifying parameters and variables	−0.12	0.08	−0.47	0.64
Collecting data	0.35	0.10	0.62	0.53
Interpreting data and graphics	0.24	0.16	0.20	0.85
Hypothesis generating				
Describing and recognizing of relations	−0.58*	−0.13	−1.24	0.21
Thinking of alternative answers	0.09	−.49	1.47	0.14
Proposing an answer	0.55*	−0.09	1.66	0.10
Formulating hypotheses	0.61**	−.27	2.31	0.02*
Thinking of alternative hypotheses	−0.01	−0.01	0.00	
Hypothesis testing				
Experimental design	−0.24	−0.49	0.68	0.50
Predicting	0.16	−.40	1.37	0.17
Collecting data	0.55*	0.20	0.97	0.33

Table 8. Continued

	SWLE			
Communicative activities	Experimental group	Control group	Z^a	*p*
Conclusion				
Interpreting data and graphics	−0.22	−0.20	−0.05	0.96
Rejecting hypotheses	−0.00	0.11	−0.26	0.80
Concluding	0.39	−0.06	1.10	0.27
Total	0.46	−0.15	1.52	0.13
Discovery regulative learning				
Orientation	0.20	−0.22	1.00	0.32
Monitoring	0.05	−0.42	1.16	0.24
Planning	0.30	0.04	0.63	0.53
Evaluation	0.04	−0.12	0.38	0.71
Total	0.18	−0.34	1.25	0.21
Asymmetry in communication	0.42	0.61*	−0.61	0.54

*$p < 0.05$, **$p < 0.01$.
[a] Z scores computed for the differences of Fisher's Z' scores for both sets of correlations.

and better learning results. The instructional program is centered on the RIDE rules: *Respect, Intelligent collaboration, Deciding together*, and *Encouraging*. The results of our study show that the instruction indeed leads to more effective communicative activities. Learners receiving the RIDE instruction use more communicative activities associated with the RIDE rules, especially those associated with *Deciding together* (D) and *Encouraging* (E). These learners asked more questions than did the learners not receiving the RIDE instruction. Among the questions asked by the experimental group were requests for agreement, open questions, critical questions and questions after incomprehension. The experimental group also gave more informative answers, agreed more often, and asked their partner more often to perform an action in the learning environment. As mentioned by several researchers (Webb & Farivar, 1994; Mercer, 1996; King, 1997; Baker et al., 1999; Wegerif et al., 1999; van Boxtel et al., 2000; Veerman et al., 2000) these activities should contribute to more effective learning. This indicates that that these learners were working more collaboratively than the control group. Thus, the first part of the research question, whether the instruction leads to improved communication, can be answered in some ways. This finding is in line with other studies in which learners benefited from instruction in effective communication, but in which communication took place face-to-face, rather than through chat (e.g., Hoek, 1998; Mercer, 1996; RojasDrummond & Mercer, 2003; Swing & Peterson, 1982; Wegerif et al., 1999).

The second research question, whether this improved communication leads to a more productive discovery process, requires a more complicated answer. We see an increase in a few transformative discovery processes (describing and recognizing of relations, and concluding) and an overall increase of regulative processes in the experimental group, indicating that the improved communication resulting from the instruction leads to more regulation of the learning process. As computing a number of variance analyses increases the probability of chance capitalization, we have to point out that the results with respect to the increase of transformative discovery processes should be interpreted with care.

We also see another important effect in the data. We find a number of correlations between communicative activities associated to the RIDE rules with transformative and regulative discovery learning activities, especially for *Intelligent collaboration* (I). These correlations are found for learners in both groups. The correlations indicate that there is a positive relationship between *Intelligent collaboration*, which includes informative responses, learners asking for understanding, argumentative activities and informative activities, and the occurrence of productive discovery processes. In an earlier study of Saab et al. (2005) almost the same correlations were found between the communicative activities represented by the rule *Intelligent collaboration* and the discovery activities mentioned. Relations between the rules *Deciding together* and *Encouraging*on the one hand and the transformative discovery activity concluding and the regulative discovery activities monitoring and planning on the other hand were found, too. The use of these activities were also induced by the instructional program, since they were significantly more used in the group that received the instructional program. However, while the instruction has the greatest effect on the D and E part of the RIDE rules, the I part seems to have the most influence on discovery processes.

We did not find significant differences between the experimental and the control group for results of working within the learning environment (the SWLE score). A possible explanation of this may be that the learners did not spend a sufficiently long time within the learning environment to realize to the full the potential of the learning environment to change the discovery process. Moreover, learning to apply the RIDE rules may have increased the load on the learners who received this instructional program. The learners that received the RIDE rules were given prompts during the learning process. Although prompting rules can have a positive effect (cf. Howe & Tolmie, 1998), it takes time to read them and follow up the instruction, which can result in finishing fewer assignments in a fixed amount of time. Kozma (1991) found that not all learners make use of or respond to prompts in a similar way. In this study, in which Kozma examined the impact of computer-based tools and embedded prompts on college writers, it was found that novices responded to the prompts differently than advanced writers. Thus, learners' use of prompts also depends on their existing skills and knowledge. Therefore, differences in learners' prior skills and knowledge should be taken into account when designing supportive measures for collaborative discovery learning. Not all support is likely to be equally effective for all kinds of learning. In our study, it is possible that learners were given not enough time to acquaint themselves with the support offered, meaning that during the experimental session, they could give less attention than needed to construct new knowledge.

When investigating the relation between communicative and discovery learning processes and the SWLE score, we see a difference between the groups. The SWLE correlates in the experimental group with informative, hypothesis and answer generating activities, as well as with collecting data, whereas there are no significant relations between activities and SWLE in the control group. Between the experimental and control groups, there is a significant difference in correlations for formulating hypotheses. In the experimental group, learners who often formulated hypotheses had better learning results while working with the learning environment. A similar relation was not found in the control group. This indicates that learners who received the instructional program were able to use this activity more effectively than learners who did not receive this instructional program.

In the control group we found that a high score on SWLE was positively related with an unbalanced amount of utterances. In cases where one dominant participant did most of the chatting, the learning results within the learning environment were better than in cases where both participants contributed evenly. This suggests that the collaboration in the control group has a detrimental effect on the learning process and that good score on SWLE was almost completely due to the effort of one participant. Such an effect was not found in the experimental group.

We can conclude from this study that the RIDE instruction leads to more constructive communication, and more and effective discovery learning activities, but not directly to better discovery learning results. The RIDE instruction supported the communication leading to a more productive discovery learning process.

This study explored the potential of providing instruction on communication in order to improve the performance in collaborative discovery learning environments. We found that instructing learners in how to communicate effectively can result in improved communication and that this may give rise to better discovery learning, but still these effects on discovery processes and results are indirect and somewhat limited. Therefore, a possible next step to take is to design a learning environment in such a way that the beneficial communicative activities are elicited by the communication instructional program, for example, by letting the learners practice more often with the RIDE rules, as well as by cognitive tools that elicit communicative actions in the specific discovery learning context.

Notes

1. "Collisions" was developed by Hans Kingma and Koen Veermans (Universiteit Twente). SimQuest was developed in the SERVIVE project coordinated by the Universiteit Twente.
2. Both tests were developed by Janine Swaak (Swaak, 1998).

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