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Supporting Students Working Together on Math with Social Dialogue

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Abstract

In this paper, we describe an environment for supporting collaborative problem solving that uses dialogue agents both for creating a collaborative attitude between students as well as for offering instruction. We evaluated the effect of the social dialogue agents on student collaboration by contrasting a condition that included the social agents with a condition that did not include them. Both conditions involved dialogue agents for offering math instruction. Our finding is that the social agents changed the attitude students displayed towards one another as well as their perceptions of how much help they gave a received. There was some weak evidence suggestive of a positive learning effect.

Index Terms: tutorial dialogue, computer supported collaborative learning

1. Introduction

The study we report in this paper is one in a series of investigations into the design, implementation, and evaluation of conversational agents that play a supportive role in collaborative learning interactions [1,2,3]. The ultimate goal of this long term endeavor is to support collaboration in a way that is responsive to what is happening in the collaboration rather than behaving in a "one size fits all" fashion, which is the case with state-of-the-art static forms of collaborative learning support such as assignment of students to roles [4], provision of static prompts during collaboration [5], or design of structured interfaces including such things as buttons associated with typical "conversation openings"[6].

While there has been much work evaluating a wide range of conversational agents for supporting individual learning with technology [7], a similar effort in collaborative contexts is just beginning [2,3]. We have observed in our recent research that working collaboratively may change the way students conceptualize a learning task and how they respond to feedback [8]. For example, Wang et al. (2007) found that students who worked in pairs approached an idea generation task more broadly than they did when they engaged in the same task as individuals. In particular, they behaved in a way that indicated more of a fluid boundary between tasks, whereas students who worked individually focused more narrowly on one task at a time. Correspondingly, students who worked in pairs with feedback showed even more evidence of a connection between tasks, where individuals with feedback during idea generation simply intensified their success within their original narrow focus. This difference in how students responded to feedback when they worked individually and in pairs tells us that before we will be able to effectively support collaborative learning with tutorial dialogue and other intelligent tutoring technology, we must re-evaluate established approaches to determine how they must be modified in order to be successful in a collaborative context.

For decades a wide range of social and cognitive benefits have been extensively documented in connection with collaborative learning, which are mediated by conversational processes. Based on Piaget's foundational work [9], one can argue that a major cognitive benefit of collaborative learning is that when students bring differing perspectives to a problem solving situation, the interaction causes the participants to consider questions that might not have occurred to them otherwise. This stimulus could cause them to identify gaps in their understanding, which they would then be in a position to address. This type of cognitive conflict has the potential to lead to productive shifts in student understanding. Related to this notion, other cognitive benefits of collaborative learning focus on the benefits of engaging in teaching behaviors, especially deep explanation [10]. Other work in the computer supported collaborative learning community demonstrates that interventions that enhance argumentative knowledge construction, in which students are encouraged to make their differences in opinion explicit in collaborative discussion, enhances the acquisition of multi-perspective knowledge [5]. Furthermore, based on Vygotsky's seminal work [11], we know that when students who have different strengths and weaknesses work together, they can provide support for each other that allows them to solve problems that would be just beyond their reach if they were working alone. This makes it possible for them to participate in a wider range of hands-on learning experiences.

Because of the importance of these conversational processes, in our evaluation of the design of conversational agents for supporting collaborative learning, we must consider both the learning that occurs when individuals interact with these agents in the midst of the collaboration (i.e., learning from interaction with the agents) with learning that is mediated by the effects of the agents on the interaction between the students. While in our previous recent studies we have focused on the first source of learning, in the study reported in this paper, we focus on learning from changes in conversational processes.

2. Infrastructure and Materials

In this section we discuss this experimental infrastructure, which was used to conduct our investigation. We will discuss this infrastructure both in terms of the technology we used and

in how we set up the lab where the students worked. The study we report in this paper was a classroom study where students worked in their school computer lab in pairs using the collaborative problem solving environment.

The interface of the collaborative problem solving environment included two panels. On the left is a chat interface, which allows students to interact with each other as well as with the conversational agents that are triggered at different occasions during the problem solving session. The panel on the right is a structured problem solving interface that allows students to collaboratively work on a given problem. The problem solving interface in the right panel was built using the Cognitive Tutor Authoring Tools (CTAT) [14]. The structured problem solving CTAT panel has a problem layout and a hint button. The hint button triggers support built into the CTAT environment. The hint messages that are provided by CTAT are displayed in the Chat buffer. Both panels of the interface maintain a common state across both the participants at all times so that both students are independently able to manipulate all of its interface elements. All actions performed by a student in either of the panels are immediately communicated and reflected on the interface of the other student. This integrated shared experience of problem solving is in contrast to systems used in our earlier experiments that relied on VNC to coordinate the shared problem solving space [1,2].

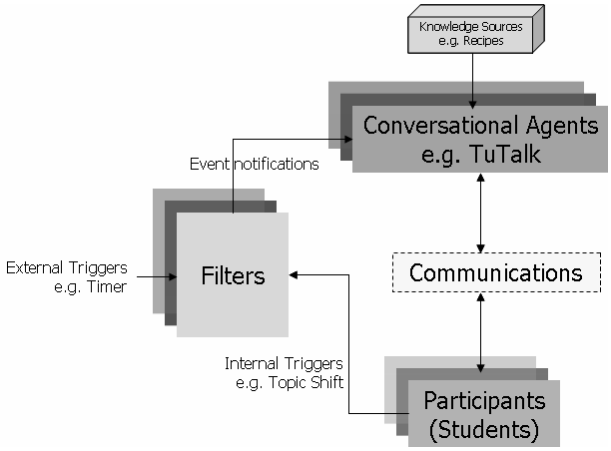


Figure 1. Architecture underlying the Collaborative problem solving interface with Conversational Agents

Figure 1 shows an overview of the architecture used to develop the infrastructure for this study. This architecture is principally similar to that used in our earlier work [1]. However the present implementation of this architecture allows for a richer set of communications that enable creation of the integrated shared problem solving experience. The filters module is responsible for managing the interaction. All interface events resulting from student contributions to the chat interface and to the structured problem solving interface are sent to the Filters module. Its purpose is to identify significant events in this stream that it then reflects back to the interfaces of both students. It also uses these identified events to update its internal state. Other triggers such as timers that keep track of time elapsed since the beginning of the session or since the last significant contribution of each student are also used to manipulate the Filter module's internal state. The internal state then is used to select strategies for selecting dialogue agents to participate in the chat session. In our prior experiments we have used different kinds of triggers including topic based filters, time-outs, interface actions, and conversational actions that are indicative of the degree of engagement of the students in the discussion. Some of these event identifiers rely on functionality provided by the TagHelper tools verbal protocol analysis toolkit [15,16]. Our generic architecture is meant to be easily extended to work with other types of triggers such as cues from other modalities like speech, eye-gaze, etc. We continue to improve the architecture to provide richer communication and modularization.

We employ two types of conversational agents for this experiment: simple social dialogue agents and cognitive support gents implemented with the TuTalk authoring environment [12,13]. The social dialogue agents were designed to show a personal interest in the students by asking them to reveal their personal preferences about things like food and extra-curricular activities. These agents simply prompted students with a question such as, "Would you prefer pizza or hamburgers for dinner?" Strict turn taking is enforced in this social dialog and a robust understanding module is used to map the student responses to one of the expected answers.

The cognitive support conversational agents were authored with the TuTalk dialogue agent authoring system [12,13]. The TuTalk agent can lead a student through a knowledge construction dialogue, which is an interactive directed line of reasoning meant to lead a student to understand a concept, such as fraction division. As displayed in Figure 1, when the Filters module sends a notification to the Conversational Agents module to trigger a particular cognitive support agent, the scheduled TuTalk agent is appended to a queue of TuTalk Agents. The TuTalk agents in the queue act upon completion of the problem in the problem solving interface and executes those agents one by one before starting the next problem. This strategy is motivated by the intention of not interrupting an ongoing conversation among the students. A sequence of turns resulting from a typical interaction with a TuTalk agent is shown below.

Tutor: *Another way to think of dividing by fractions is this: If I have 1 divided by 1/2, can I turn that into something divided by 1?. If I want to turn the denominator, which is 1/2, into 1, what do I need to do to it?*

Student 1: yep

Tutor: *Actually, you need to multiply by two. And If I multiply the denominator by 2, what do I have to do to the numerator?*

Student 1: 2

Tutor: *Right. So 1 divided by 1/2 is the same as 2 divided by 1. So that is one reason why the flip and multiply strategy for dividing by fractions works. If you multiply the denominator by something to turn it into 1, you have to multiply the top by the same value. So let's try another one. If I want to divide something by 2/3, what do I need to multiply the numerator and denominator by?*

Student 1: 3

Tutor: *Actually, it is 3/2. You should think about why.*

All communication between students in this study was through typed chat using the collaborative problem solving

environment. The arrangement of the lab in which our study was conducted was such that each student was sitting at his own computer in such a way that collaborating pairs could not easily talk face-to-face. In all cases there was a row of desks with computers in between a student's row and the row where the partner student was sitting. The students were not told who their partner was or where they were seated, and they were asked not to reveal their identities, although in some cases they did.

3. Methodology and Results

3.1. Experimental Design

The purpose of our study was to test the effect of social prompts on student interactions with each other and with the cognitive support agents during math problem solving. Our experiment was a simple two condition between subjects design in which students in the experimental condition experienced interaction with social agents in between math problems during two collaborative problem solving sessions, and students in the control condition did not.

In the experimental condition, a social dialogue agent was notified when the student interface was ready to begin a new problem. The social dialogue agents took the students through a directed system initiative dialogue to elicit their preference on certain items. Based on the students' preferences, the next math problem offered to the pair was formulated to include the given responses to the social prompts. For example, the agent might ask, "Student 1, if you had to choose between a long flight or a long car ride, which seems more uncomfortable?" The student might indicate that a car ride would be preferable. Then the tutor agent might ask, "Student 2, which are more entertaining–books or movies?", and the student might respond that books are more amusing. These two pieces of information were then used to fill in slots in a template that was then used to generate the math problem that would finally be displayed in the structured problem solving panel. In this case, the resulting story problem might say, "Jan packed several books to amuse herself on a long car ride to visit her grandma. After 1/5 of the trip, she had already finished 6/8 of the books she brought. How many times more books should she have brought than what she packed?" The goal of the social dialogs was to give students the impression that the support agents were taking a personal interest in them and that they had the opportunity to work together to create the math problems they were solving.

In order to control for content and presentation of the math content, we used the same problem templates in the control condition, but rather than presenting the social prompts to the students, we randomly selected answers to the social questions "behind the scenes" from the same set of choices offered to the students in the experimental condition. Thus, students in both conditions worked through the same distribution of problems.

3.2. Experimental Procedure

The experimental procedure extended over 4 school days, with the experimental manipulation taking place during days two (i.e., Lab Day 1) and three (i.e., Lab Day 2). The fourth day of the experiment was separated from the third day of the experiment by a weekend. Teams remained stable throughout the experiment. The students were instructed that the teams would compete for a small prize at the end of the study based on how much they learned and how many problems they were able to solve together correctly. The second and third days were lab days in which the students worked with their partner. Each lab session lasted for 45 minutes. At the end of each lab period, the students took a short quiz, which lasted about 10 minutes. At the end of the second lab day only, students additionally filled out a short questionnaire to assess their perceived help received, perceived help offered, and perceived benefit of the collaboration. On the fourth experiment day, which was two days after the last lab day, they took a post test, which was used for the purpose of assessing retention of the material.

3.3. Subjects and Materials

Thirty sixth grade students from a suburban elementary school participated in the study. Students were arranged into pairs by the experimenter in such a way as to maintain a roughly consistent average grade so far in the course between pairs, and a balanced average grade so far in the course per condition.

The materials for the experiment consisted of the following:

- A mathematics tutoring program covering problems on fraction addition, subtraction, multiplication, and division.
- 2 extensive isomorphic tests (Test A and Test B) were designed for use as the pre-test and the post-test. Likewise, we had Quiz A and Quiz B, which were designed to be isomorphic to a subset of the pre/post tests. Thus, quizzes are shorter versions of the tests. Thus, we were able to use gains on quizzes to measure learning within sessions and pre to post test gains as a measure of retention (since there was a two day lag between the last lab day and the post-test).
- Questionnaire. As a subjective assessment of socially oriented variables, we used a questionnaire with 8 questions related to perceived problem solving competence of self and partner, perceived benefit, perceived help received, and perceived help provided. Each question consisted of a statement such as "The other student depended on me for information or help to solve problems." and a 6 point scale ranging from 0, labeled "strongly disagree", to 5, labeled "strongly agree".

3.4. Results

Table 1 Questionnaire Results

	Control	Experimental
Perceived Self Competence	4.2 (.56)	4.1 (.23)
Perceived Partner Competence	4.3 (.62)	3.9 (.49)
Perceived Benefit of Collaboration	4.5 (.74)	4.4 (.70)
Perceived Help Received	1.8 (1.3)	3.3 (.69)
Perceived Help Provided	1.8 (1.1)	3.1 (1.1)

We began our analysis by investigating the socially oriented variables measured by means of the questionnaire, specifically

perceived problem solving competence of self and partner, perceived benefit, perceived help received, and perceived help provided. Recall that students responded to each question using a 6 point likert scale, ranging from 0, which signified strong disagreement, to 5, signifying strong agreement. The only significant differences were in terms of perceived help received and perceived help provided. Students in the experimental condition rated themselves and their partner significantly higher on offering help than in the control condition.

In order to investigate whether students in the experimental condition offered each other more help, two coders coded the chat logs from each lab day by consensus coding with a coding scheme consisting of 5 mutually exclusive categories, namely (R) Requests received, (P) Help Provision, (N) No Response, (C) Can't Help expression, and (D) Deny Help expression. Along with the "other" category, which indicates that a contribution does not contain either help seeking or help providing behavior, these codes can be taken to be exhaustive. Our finding was that the average number of help provisions was not significantly different between conditions. However, there were significantly more episodes in the control condition transcripts where help was not offered (Mean Control = 40.2, Mean Experimental = 24.7, $F(1,62) = 3.46$, $p = .001$, effect size .8 s.d.). Thus, the students in the control condition may have perceived less help behavior because there was a lower proportion of helping behavior. Overall, we observed that students displayed more negative affect in the control condition. Insults like "looser", "you stink", "stupid" only occurred in the control condition based on a keyword search analysis.

The learning gains analysis offers some weak evidence in favor of the experimental condition on learning. The trend was consistently in favor of the experimental condition with ANCOVA analyses comparing Quiz 1 across conditions with pretest as a covariate, Quiz 2 using Quiz 1 as a covariate, and posttest using pretest as a covariate, although none of these comparisons were statistically significant. The strongest effect we see is on lab day 2 where students in the experimental condition gained marginally more on the segment of the test related to interpretation problems ($p=.06$, effect size .55 s. d.).

4. Conclusions and Current Directions

In this paper we report on a study investigating the effect of social agents on conversational processes in a collaborative problem solving environment. Our finding was that while the social prompts encode no instructional material, they were not just extraneous entertainment either. The social prompts affected student attitudes and behavior towards each other. Furthermore, our study provides some weak evidence in favor of social prompts in connection with student learning.

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