12th International Conference on Intelligent Tutoring Systems
Honolulu, Hawaii, June 5-9, 2014

Collaboration on Procedural Problems May Support Conceptual Knowledge More than You May Think

Jennifer K. Olsen[1], Daniel M. Belenky[1], Vincent Aleven[1], and Nikol Rummel[12]

[1]Human Computer Interaction Institute, Carnegie Mellon University, Pittsburgh, PA, USA
jkolsen@cs.cmu.edu, dbelenky@andrew.cmu.edu, aleven@cs.cmu.edu
[2]Institute of Educational Research, Ruhr-Universität Bochum, Germany
nikol.rummel@rub.de

Abstract. While collaborative Intelligent Tutoring Systems (ITSs) have been designed for older students and have been shown to support sense-making behaviors, there has not been as much work on creating systems to support collaboration between elementary school students. We have developed and tested, with 84 students, individual and collaborative versions of an ITS that supports students' learning of equivalent fractions. The current paper presents preliminary data analysis focused on understanding what design patterns are associated with sense-making behaviors. Triangulating between log data, eye-tracking data, and transcript data, we find evidence of sense-making behaviors for students who work collaboratively on procedural problems as shown by a correlation of increased levels of joint visual attention and conceptual learning gains, longer time spent on hints compared to students working individually, and example dialogue. Future work will examine collaborative episodes more closely to isolate design features that are beneficial for elementary school students.

Keywords: Problem solving, collaborative learning, intelligent tutoring system, elementary school students

1 Introduction

Collaborative learning has been shown to be beneficial in face-to-face and Computer Supported Collaborative Learning (CSCL) settings [6], [14]. However, supporting good collaboration, even in a CSCL environment, is challenging. Collaboration often does not happen spontaneously, and collaboration scripts are often used to support students in their learning by scaffolding the tasks and interactions between group members [3]. It is important for these scripts to match both the learning goals of the activity and the developmental level of the students. To date, much of the research on supporting collaboration has been done with older students and it is an open question how elementary school students can successfully take advantage of collaboration. To address this issue, we focus on how to best scaffold sense-making behaviors, as collaboration is often successful when these learning behaviors are elicited. That is, when good collaboration occurs, we would expect to see more evidence of these behaviors in dialogue, as well as in other data streams. By analyzing different data streams from elementary school student's collaborations, we can better understand what differentiates successful dyads from those that are less successful and how best to support these interactions in a CSCL environment for this age group.

Although the Common Core educational standards that most US states have adopted expect elementary school students to collaborate, it is still unclear how to best provide collaborative support for this age group. Collaboration is used less in elementary school classrooms, partially because of the additional challenge it can bring in terms of class management. Elementary school students are at a different developmental stage both cognitively and socially than older students, so it is unclear if the same types of support that are beneficial to older students would apply to younger students as well. There have been some successful collaborative paradigms that have focused on elementary school students, such as reciprocal teaching, but these are often not supported in a CSCL environment [10].

We developed a collaborative Intelligent Tutoring System (ITS) to support the learning of fractions for 4^{th} and 5^{th} grade students. Support was provided for the collaboration through an embedded collaboration script designed to match the learning goals of the problem sets. We found that students working collaboratively had equivalent learning gains to those who worked individually [9]. To better understand how to improve the provided support for collaboration with elementary school students, we collected log data, eye-tracking data, and transcript data as students worked with our ITS. Because collaboration is often successful through students' mutual elaborations and explanations that can lead to sense making, in the present paper, we examine this data for evidence of sense-making behaviors both within the transcripts and in terms of visual joint attention and time spent on a requested hint. By triangulating this data and looking for the moments of good collaboration, we are better able to find what successful elementary school students do and how best to support these actions. We would expect to find more evidence of sense-making behaviors as students work on conceptually-oriented problems than procedurally-oriented problems because these behaviors would support the making of deeper connections needed for conceptual knowledge more than the fluency needed for procedural knowledge.

2 Methods

2.1 Collaboration Support

Informed by prior work on the Fractions Tutor [11], we developed an ITS to support the learning of equivalent fractions. We developed two parallel versions, one for collaborative learning and one for individual learning. Each version included the cognitive support that is typical of an ITS, such as step-by-step guidance and on-demand hints, while the collaborative tutor also provided support for collaboration through an embedded collaboration script. Each ITS included two problem sets targeted at the learning of conceptual knowledge or procedural knowledge. The collaborative tutors support synchronous collaboration, in which paired students sit at their own computer and have a shared view of the problem while collaborating through audio chat.

The collaboration scripts consisted of a subset of three collaboration features: roles, unique information, and cognitive group awareness. Roles assigned specific tasks to group members while unique information provided different information to each student for a sense of accountability. Cognitive group awareness was supported through each student answering a question independently before seeing their partner's answer and then choosing a group answer. The problems targeting conceptual knowledge included all three features, while procedural problems were supported through the collaboration features of roles and unique information. The different features were chosen for the conceptual and procedural problem sets to best support the type of knowledge being targeted. Cognitive group awareness was used to scaffold only the conceptual problems because providing the opportunity to discuss differing answers provides more support for behaviors that lead to sense making than to fluency. Because there was more support for activities that can lead to sense making in the conceptual problems, we may expect to see more evidence of these behaviors in the conceptual problems than in the procedural problems.

2.2 Experimental Design and Procedure

Participants in the study were 84 4th and 5th grade students, ranging from 9-12 years old (M = 9.96, SD = .75) from two US elementary schools. The students participated in "pull-out" sessions (in a lab room set up in the school) during normal school hours where they worked for 45 minutes with a version of our ITS. Students were assigned to pairs based on their teachers' pairings, and each pair was randomly assigned to one of four conditions, by crossing two factors; collaborative or individual instruction and problems geared towards conceptual knowledge or procedural knowledge. We developed two computer-based isomorphic test forms that matched the target knowledge taught in the tutors.

3 Results

To analyze the behaviors during the tutor task that may be indicative of sense making, we looked at the data logs, the eye-tracking data, and are beginning to analyze the transcripts from the collaborative groups. Across all data types, the procedural and conceptual conditions were analyzed separately because of the different tutor problem designs. The tutor log data was analyzed to interpret the hint behavior in the different conditions. Specifically, the time spent per hint was analyzed since hint requests often happen at times of problem solving impasses, which may be good occasions for learning, and more time on hints can be a signal of behaviors that lead to sense making such as discussion or self-explanation. For the conceptual conditions, the students working individually (IC) requested significantly more hints than those working collaboratively (CC), $t(23.0) = 2.38$, $p = .03$, while in the procedural conditions the students working individually (IP) asked for marginally more hints than the students working collaboratively (CP), $t(27.8) = 2.00$, $p = .06$. However, for the two conceptual conditions, there was no significant difference between the CC and IC conditions on average time spent per hint requested, while for the procedural condition, there was a significant difference between the CP and IP conditions on the amount of time spent per hint, $t(26.7) = 2.64$, $p = .01$. The CP condition spent significantly more time per hint level with a mean of 13.38 seconds compared with the individual condition mean of 6.50 seconds (see Figure 1). This longer time spent on each hint may be a signal that more productive collaboration, which supports sense-making learning processes, was occurring during these collaborative procedural sessions.

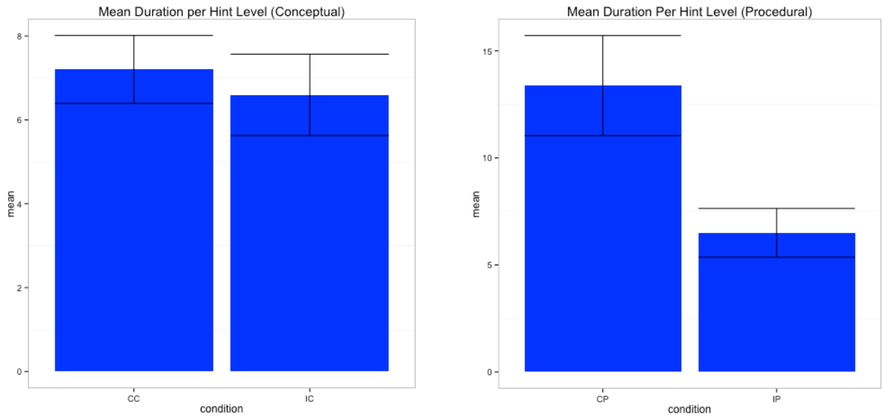

Fig. 1. Time spent per hint was significantly higher in the collaborative procedural condition.

In addition to analyzing what tutor log data might reveal about student collaboration, we are exploring the utility of using joint visual attention measures as an index of collaboration quality, consistent with Nüssli [8]. We extracted a measure of joint attention, defined as the amount of time the students spent looking at the same area of the screen at the same time. Because a variable number of problems were completed by each dyad, as a preliminary measure, we averaged the joint attention of the first four problems. Another paper provides a more detailed analysis of the eye-tracking data [1]. While joint attention correlated with total test scores (i.e., conceptual and procedural items), there was no correlation between the amount of joint attention and the procedural test items, $r = .14$, $p = .491$. Surprisingly, for the procedural condition, there was a correlation between the joint attention and the conceptual test items, $r = .35$, $p = .072$, but this was not observed for the conceptual condition, $r = .08$, $p =. 777$. Since joint visual attention indicates that students are visually attending the same area, more joint attention may indicate that dyads are participating in activities that require both students' attention, such as discussions that may lead to more sense making.

We also have begun to analyze the transcripts from the audio data for moments of good collaboration as defined by past research [2], [7], [13]. To begin the preliminary analysis, we looked at an example dyad that had a high average duration per hint. Within this transcript, we saw signs of more interactive learning through the use of questions and answers. Below is an excerpt representative of some of the discussions between the students. Within context, the students have been asked to multiply 4/7 to find equivalent fractions.

Student 2: I think it means the first fraction, um...times one…in the instructions
Student 2: um…
Student 1: I…still don't…wait…
Student 1: I still don't get it.
Student 2: Um, try the purple fraction times the…times one

Student 2 first explains to their partner in broader terms about how to complete the step and points out the information in the instructions before providing additional help with a more specific hint.

4 Discussion and Conclusion

Through preliminary data analysis, we have seen evidence of sense-making behaviors during collaborative procedurally-oriented tasks that may lead to better conceptual knowledge. During procedural problem solving, the students in the collaborative condition spent more time per hint than the students working individually. This difference on the duration spent on each hint might be because the students are spending more time discussing and making sense of the hint in the collaborative condition. In the eye-tracking data, we see that the students working collaboratively on procedurally-oriented problems, there is a correlation between joint attention and conceptual learning gains. Since joint attention may be a measure of better collaboration and since we did not see this correlation in the conceptual instruction condition, collaboration may, surprisingly, have been more important to gain conceptual knowledge with procedurally-oriented problems than with conceptual-oriented problems.

Conceptual and procedural learning are related through an iterative relationship [12]. Learning conceptual knowledge can transfer to procedural skills while learning procedural skills can transfer to conceptual knowledge. However, the relationship is not symmetrical and the gains may be greater when learning conceptual knowledge [12]. In our study, it may be that the procedural tutor provided less support for gaining conceptual knowledge leaving room for collaborating students to engage in productive sense making, as illustrated in the example dialogue of students. Collaboration may be most successful when it supports activities that lead to more sense making, which can be beneficial for conceptual knowledge. Since the procedural problems did not already provide the scaffolding for conceptual knowledge acquisition and sense making, the students may have found support for sense making through collaboration. The results of more joint attention and longer hint duration in the procedural condition and not the conceptual condition support this position.

By triangulating three data streams, we see preliminary evidence of good collaboration within the procedural condition. Currently these measures of collaboration are imperfect and more analysis is needed to pinpoint the somewhat surprising trends we have seen of better collaboration during procedural tasks. By continuing analysis on the transcripts, specifically contrasting cases where we are seeing evidence of this good collaboration with those where we do not, patterns may emerge of what successful dyads are doing compared with less successful dyads. This dialogue data along with the tutor log data may provide insights into how best to support collaboration with elementary school students. It is important to look at both the design features that may correspond with moments of good collaboration and to also find patterns in good collaborating dyads that are not present in other dyads that could then be better supported in the problems. Future work will focus on analyzing the dialogue and tutor log data to find features to better support collaboration with elementary school students.

Acknowledgments. We thank the Cognitive Tutor Authoring Tools team, Amos Glenn, and Ann Lin. This work was supported by Graduate Training Grant # R305B090023 and by Award # R305A120734 both from the US Department of Education (IES).

5 References

1. Belenky, D.M., Ringenberg, M., Olsen, J., Aleven, V., & Rummel, N.: Using dual eye-tracking to evaluate students' collaboration with an intelligent tutoring system for elementary-level fractions. Paper submitted to the 36th Annual Meeting of the Cognitive Science Society (submitted)
2. Chi, M. T.: Active‐constructive‐interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science*, *1*(1), 73-105 (2009)
3. Dillenbourg, P. & Jermann, P.: Designing integrative scripts. In F. Fischer, I. Kollar, H. Mandl & J. Haake (eds.) Scripting computer-supported communication of knowledge. Cognitive, computational, and educational perspectives, pp. 275-301, New York: Springer (2007)
4. Kollar, I., Fischer, F., & Hesse, F. W.: Collaboration scripts–a conceptual analysis. Educational Psychology Review, 18(2), 159-185 (2006)
5. Janssen, J., & Bodemer, D. Coordinated computer-supported collaborative learning: Awareness and awareness tools. Educational Psychologist, 48(1), 40-55 (2013)
6. Lou, Y., Abrami, P. C., & d'Apollonia, S.: Small group and individual learning with technology: A meta-analysis. Review of educational research,71(3), 449-521 (2001)
7. Michaels, S., O'Connor, C., & Resnick, L. B.: Deliberative discourse idealized and realized: Accountable talk in the classroom and in civic life.*Studies in Philosophy and Education*, *27*(4), 283-297 (2008)
8. Nüssli, M.-A.: Dual eye-tracking methods for the study of remote collaborative problem solving. (Doctoral dissertation). doi: 10.5075/epfl-thesis-5232 (2011)
9. Olsen, J. K., Belenky, D. M., Aleven, A., & Rummel, N.: Using an intelligent tutoring system to support collaborative as well as individual learning. In Intelligent Tutoring Systems, (in press).
10. Palinscar, A. S., & Brown, A. L.: Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and instruction*,*1*(2), 117-175 (1984)
11. Rau, M., Aleven, V., Rummel, N., & Rohrbach, S.: Sense making alone doesn't do it: Fluency matters too! ITS Support for Robust Learning with Multiple Representations. In Intelligent Tutoring Systems, pp. 174-184. Springer Berlin/Heidelberg (2012)
12. Rittle-Johnson, B., & Alibali, M. W.: Conceptual and procedural knowledge of mathematics: Does one lead to the other? Journal of educational psychology, 91(1), 175-189 (1999)
13. Rummel, N., Deiglmayr, A., Spada, H., Kahrimanis, G., & Avouris, N.: Analyzing collaborative interactions across domains and settings: An adaptable rating scheme. In Analyzing interactions in CSCL, pp. 367-390, Springer US (2011)
14. Slavin, R. E. Research on cooperative learning and achievement: What we know, what we need to know. Contemporary educational psychology, 21(1), 43-69 (1996)