Different Types of Collaborative Problem-Solving Processes in an Online Environment: Solution-oriented versus Problem-oriented

Abstract

The purpose of this study was to investigate the types of problem-solving behaviors and their effects on solution quality in an online collaborative learning context. A total of twelve pre-service teachers enrolled in a computer education course participated in the study. Students in pairs, randomly assigned by the instructor, carried out a problem-solving task and then changed partners for subsequent tasks. The problem-solving processes of twenty-five pairings of students were analyzed. Data on their problem-solving behaviors, the quality of their solutions, and their domain knowledge was collected. Results revealed that students who demonstrated more solution-oriented behaviors led others to better solutions while collaborating. In contrast, students who had difficulty understanding problems demonstrated more problem-oriented behaviors. The solution-oriented students also gained better domain knowledge at the end, compared to the problem-oriented ones. The effects of the student's interactions during the problem-solving process were discussed.

Running head: Collaborative Problem-Solving Processes

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Problem solving is one of the essential skills that people should have to be successful in their daily and professional lives (Jonassen, 2000). Problem solving serves as an instructional practice where students can discover appropriate ways to achieve a goal, frequently through collaboration in group settings. Since collaborative learning is considered an effective learning strategy that enhances student interaction and facilitates deep understanding through the elaboration process, many instructors have adopted collaborative problem-solving activities, even in online learning environments (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Hmelo-Silver, 2004; Schoenfeld, 1992).

To find ways to facilitate effective problem-solving collaborations in online learning environments, it is crucial to understand students' interaction patterns. An investigation into student interactions would help clarify instruction design solutions that promote students' positive interactions in collaborative online learning. Although researchers have investigated the effects of an instructor's interventions and use of collaboration tools that visualize group processes (Dehler, Bodemer, Buder, & Hesse, 2011), the impact of self and peer assessment on collaboration (Phielix, Prins, Kirschner, Erkens, & Jaspers, 2011), and metacognitive guidance (Kwon, Hong, & Laffey, 2013), it is still unclear how students interact with each other, specifically when solving problems collaboratively in online learning environments, and how these affect learning. Therefore, by focusing on the problem-solving process, this study examines problem-solving patterns in peer interactions in collaborative learning, and the effect of these interactions on students' understanding of computer programming in an online environment.

Literature review

One of the most valued, but not fully acquired skills that prepares students for a professional work environment, is the ability to solve problems through collaboration (Hesse, Care, Buder, Sassenberg, & Griffin, 2015; Salomon & Globerson, 1989). Though educators have tried to improve students' collaborative problem-solving skills by providing diverse opportunities, students' actual collaboration tends to be below expectations (Barron, 2003; Brindley, Blaschke, & Walti, 2009; Kreijns, Kirschner, & Jochems, 2003; Salomon & Globerson, 1989). Frequently, the instructor fails to coordinate group processes, and the students eventually become reluctant to engage in group work (Barron, 2003; Kerr & Bruun, 1983). Understanding students' collaborative interactions and identifying effective patterns is crucial for the instructor to facilitate the problem-solving activity.

Problem-Solving Process

Researchers have suggested models or structures of problem-solving processes. For example, Jonassen (2000) suggested taking a broad perspective to a problem-solving process with the following structure: problem variation (e.g., well/ill-structured, complexity), representation (e.g., context, cues/clues), and individual differences (e.g., cognitive styles, general problem-solving strategies). In addition, more specific problem-solving processes have been extensively investigated (e.g., Barron, 2003; Jonassen & Kwon, 2001; Raes, Schellens, De Wever, & Vanderhoven, 2012). Hayes (1989) categorized the problem-solving process into 6 phases: finding the problem, representing the problem, planning the solution, carrying out the plan, evaluating the solution, and consolidating gains. Among those, there are two phases that significantly influence the quality of a solution: problem representation and solution development (Simon, 1978).

Problem Representation

The quality of a solution is strongly influenced by the problem representation phase (Simon & Hayes, 1976) which has been referred to as "a cognitive structure corresponding to a problem, constructed by a solver on the basis of his domain-related knowledge and its organization" (Chi, Feltovich, & Glaser, 1981, p. 122). Usually more knowledgeable students represent problems more accurately than their less knowledgeable peers as a result of their ability to categorize a problem based on its structure rather than its surface features (Chi et al., 1981). Educational studies have examined the interactions during problem representation that led to higher group performance during problem-solving tasks (Barron, 2003; Cooke & Szumal, 1994; Jonassen & Kwon, 2001; Suthers, 2006). For example, problem-centered interactional activities have a positive impact on a group's performance. Kapur and Kinzer (2007) examined the collaborative problem-solving process while focusing on the problem-centered interactional activities of sixty 11th-grade science students. The results showed that interactions exchanged early on tended to lock in the later discussion, and that affected the quality of problem solving (Kapur & Kinzer, 2007). This early interaction might be related to the group's problem representation process. Krawec (2014) revealed that the quality of problem representation, as measured by paraphrasing a problem statement or visual representation of the problem, significantly predicted the accuracy of its solution.

Solution Development

The solution development phase is also crucial to the quality of the solution. Chi, Glaser, and Rees (1982) investigated expertise in problem solving through a robust analysis of empirical evidence. They pointed out that there are considerable differences between novices and experts. For example, the novices will stick to the problem definition or problem representation even as they work on a solution whereas experts will move forward to the next process of problem solving. In the collaborative problem-solving process, these types of interactions might play a significant role. Tausczik, Kittur, and Kraut (2014) investigated collaborative interactions by examining an online mathematical problem-solving community where participants asked and answered mathematics questions. The researchers categorized these interactions into five different types of collaborative acts (i.e., providing information, clarifying the question, critiquing an answer, revising an answer, and extending an answer), and evaluated their impact on the solution quality. The results showed that solution-oriented interactions (e.g., 'revising/extending an answer') had a direct and immediate positive impact on solution quality. On the other hand, 'clarifying the question' and 'critiquing an answer' had a delayed positive impact on solution quality, and little effect on the short-term results.

When students develop solutions, they tend to search their prior knowledge or experience for understandings that can trigger a solution by mapping it onto their current problem (Bransford, Brown, & Cocking, 1999; Lazakidou & Retalis, 2010). However, they can encounter a dead end if they map it onto the wrong problem and do not consider alternatives (Kapa, 2001). Considering that novice problem solvers easily propose solutions without validating whether they satisfy specific goals or are limited by a certain constraint, checking alternatives and evaluating the effectiveness of solutions are necessary processes for successful problem solving (Ge & Land, 2003). Peer interactions that challenge one another to elaborate on their ideas can facilitate the solution evaluation process and thereby generate better solutions (Jonassen & Kim, 2010; Webb, 1982; Webb & Mastergeorge, 2003).

Interactions in Online Collaboration

As reviewed above, in the problem representation phase, a problem solver may benefit from the intensive early interactions among group members that focuses on narrowing down the scope of a problem. In addition, during the solution development process, students would be more successful if focusing on validating the solution rather than expanding on or analyzing the problem. Therefore, more task-oriented behavior in each phase would be beneficial during problem solving. The online environment might facilitate more task-oriented interactions than face-to-face interactions, which suggests that online collaboration might be as successful as face-to-face collaboration, even though it is considered challenging for students to collaborate in online environments. For example, Jonassen and Kwon (2001) compared student interactions of a face-to-face situation with an online environment during a collaborative problem-solving process. Eighteen undergraduate students formed groups of three, and solved authentic business problems. The results showed that the online collaboration groups used more task-directed and focused communications, and reflected more on the problem-solving nature of the task than the face-to-face groups. While group activities in an online collaborative learning environment have significant potential, there has been little research that examines the problem-solving interactions where collaboration takes place and how that impacts the solution. Online collaborative problem solving has not been sufficiently investigated in the instructional design literature. Investigating student interactions in online collaborative problem-solving settings would shed light on our understanding about the breadth of problem-solving activities well enough to support students in the task.

Context and Purpose of this study

This study specifically considers the research context, which targeted undergraduate students' synchronous (i.e., online conferencing) collaborative interactions during the programming related problem-solving task in an online environment. The other contextual consideration is the group setting. In order to consider the individual differences, it would be necessary to investigate each individual participant's paired activity with different group members. Considering that point, we assigned each participant to collaborate with every other peer once (i.e., dyad activity) during the semester and analyzed the interactions.

The purpose of the current study is to examine students' collaborative problem-solving interactions in an online learning environment. The interaction patterns, elaboration process for understanding problems, and validating solutions were analyzed to reveal how these affected the quality of solutions. Specifically, the following research questions are addressed.

1. What types of interactions are involved during a synchronous online collaborative problem-solving process?

2. Which types of interactions are significantly related to the solution quality?
3. Does an individual make different types of interactions during the pair work?
4. Do the types of interactions affect learning outcomes?

Method

Participants

Twelve undergraduate pre-service teachers (8 female and 4 male), enrolled in a computer educator license course, were recruited with their consent. They all had majored in different subjects and had not learned any programing languages before taking the course. They knew each other because they took computer educator license courses beforehand. The participants received no compensation for their participation.

Design

In a face-to-face class session, the participants learned the basic concepts of computer programming such as arrays, conditional statements, loops, and functions (conceptual knowledge). They also practiced writing program syntax after watching a demonstration by the instructor (syntactic knowledge). They were then asked to solve five sets of problems as a course requirement while learning the programming language. The problem-solving tasks included the debugging of erroneous syntax and completing a program by adding syntax to a blank. A total of thirty problem-solving processes (six pairs × five tasks) were administrated. However, five cases were not recorded due to technical issues and were excluded from the analysis.

A pair of students, put together by the instructor, carried out the task within a time period of one week. Students met through a synchronous online conference tool that allowed screen share, chat, and audio/video conferencing. Students had tried out the conference tool in class before carrying out the first problem-solving task.

The instructor assessed the students' conceptual understanding of the program twice. The tests were administered in the class in a written test format. The results counted toward the students' individual course grades. Table 1 illustrates the series of problems and exam schedule.

Table 1.
Sequences of problems and exams

Time	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 12
Task	Problem 1	Problem 2	Problem 3		Problem 4	Problem 5	
Topic	Variable, Array	Conditional statement	Loop		Function	Form	
Test				Exam 1			Exam 2

Measures

Problem-solving behaviors. In order to understand the students' problem-solving process and conduct content analysis, we adopted Poole and Holmes' decision-making framework (Poole & Holmes, 1995) that was also utilized by Jonassen and Kwon (2001) to classify problem-solving processes (see Table 2).

The students' written and verbal communications were recorded and analyzed with two independent coders. The unit of analysis was a meaning unit segmented by the coders that fitted into the coding scheme. Two coders independently coded with substantially reliable degree (Cohen's K = .75) and discrepancies between the coders were resolved after a discussion.

Table 2.
Coding Scheme of Content Analysis

Category	Behaviors	Code	Description
Understanding Problem	Problem detection	PD	Identify the location of problem
	Problem analysis	PA	Analyze the cause of problem
Finding Solution	Solution suggestion	SS	Suggest a solution for the problem
	Solution evaluation	SEV	Evaluate and validate the effectiveness of the solution
	Solution confirmation	SC	Agree to the solution
Using Strategy		ST	Use a strategy to solve the problem
Others		Off	Any behavior that is not directly related to the problem-solving process, such as socio-emotional expressions and off-topic interactions

Quality of solution. The solutions submitted by the students were scored based on a rubric developed by the instructor. Each problem-solving task contained four problems, which was worth four points in total.

Conceptual understanding of program. Students' conceptual understanding of the program was assessed twice with 20 multiple choice items as illustrated by Table 1.

Analysis

Student's problem-solving behaviors were analyzed in regards to two aspects: individual and group. At the group level, we considered a group as a unit of analysis. This approach allowed us to reveal how interactions between two students influence the quality of the solution. At the individual level, we examined each student's problem-solving behaviors, which allowed us to classify students on the basis of their problem-solving patterns.

Results

Problem-solving Behaviors at the Group Level

Students' problem-solving behaviors were analyzed in a total of twenty-five pairings. Initially, we examined and counted the frequency of each problem-solving behavior within each problem case. In order to reveal the relationship between the problem-solving behaviors and the quality of the solutions, we calculated the Pearson coefficients between the frequency of behaviors and the solution scores. Results revealed that there was not any statistically significant relation between the problem-solving behaviors and solution scores (Pearson coefficients ranged between -.09 and .34, $p > .05$).

Results extracted only from the frequency could bias our understanding because the total number of behaviors was quite different across groups. For example, the following case can be assumed: group A analyzed a problem (i.e., problem analysis: PA) four times while group B analyzed it five times. To solve the problem, group A demonstrated twenty behaviors in total while group B demonstrated thirty. In this case, although group A analyzed the problem less frequently than group B, the proportion of the behavior (20%) was higher than in group B (17%). In consideration of the bias, we calculated the proportion of the behaviors in each group and followed the same analysis process as discussed. Results revealed that the problem analysis (PA) behavior negatively correlated with the solution score, $r(23) = -.40$, $p = .047$.

Problem-solving Behaviors at the Individual Level

Twelve students' problem-solving behaviors were analyzed individually. As we analyzed the relation between the problem-solving behaviors and the quality of the solution from the group level, Pearson coefficients were calculated at the individual level. Based on the frequency of behavior types, the problem analysis (PA) showed a strong negative correlation with the solution score, $r(10) = -.78$, $p = .003$. Based on the proportion of behavior types, the problem analysis (PA) again showed a strong negative correlation with the solution score, $r(10) = -.82$, $p = .001$. In contrast, a solution evaluation (SEV) revealed a strong positive correlation with the solution score, $r(10) = .75$, $p = .005$.

As we were interested in the problem analysis and solution evaluation behaviors during problem solving, we conducted a cluster analysis by using the Ward Linkage method with the two behaviors as clustering variables. The cluster analysis produced two groups of individuals. Table 3 describes the characteristics of the groups in terms of problem-solving behaviors and solution scores. There was a clear contrast between the two groups: one paid more attention to evaluating solutions, $t(10) = 3.68$, $p = .004$, while the other paid comparatively more attention to problem analysis, $t(10) = 2.11$, $p = .06$. Based on the results, we named one as the "solution-oriented" group, and the other as the "problem-oriented" group. Consequently, the solution-oriented group (M=3.77, SD=.176) received higher scores on their solutions than the problem-oriented group (M=2.93, SD=.434), $t(10) = 3.63$, $p = .005$. No other statistically significant difference between the groups was found from other behaviors.

Table 3.

Problem-Solving Behaviors at the Individual Level

Cluster	N	Solution	PD	PA	SS	SEV	SC	GR	ST
Solution-oriented	4	3.77 (.176)	11.3%	5.4%	19.1%	22.2%	17.8%	18.4%	5.8%
Problem-oriented	8	2.93 (.434)	7.4%	11.2%	21.5%	13.7%	16.4%	25.6%	4.3%
Total	12	3.21 (.544)	8.7%	9.3%	20.7%	16.5%	16.8%	23.2%	4.8%

Note. PD: Problem Detection, PA: Problem Analysis, SS: Solution Suggestion, SEV: Solution Evaluation, SC: Solution Confirmation, GR: Group Regulation, and ST: Strategy.

Combination of Individuals

How students engaged in problem-solving behaviors were affected by the combination of students and how they interacted. As students were categorized into two groups (i.e., solution vs. problem-oriented), three types of combinations were possible: Only Problem-oriented group (two problem-oriented students), mixed group (one solution and one problem-oriented student), and Only Solution-oriented group (two solution-oriented students). We analyzed problem-solving behaviors based on the combination of individuals (see Table 4). The results revealed clear contrasts between the groups in the proportions of problem analysis (PA) and solution evaluation (SEV) behaviors. When two problem-oriented students collaborated, they had demonstrated more problem analysis behaviors (13%) compared to the groups having one or two solution-oriented students, 4% and 8% respectively. On the contrary, when two solution-oriented students collaborated, they focused on solution evaluation (25%) more intensively than the other groups (14% and 17%).

Table 4.
Combination of Individuals

Row Labels	N	PD	PA	SS	SEV	SC	GR	ST
Only Problem-oriented	11	07%	13%	19%	14%	16%	26%	05%
Mixed	11	10%	04%	23%	17%	19%	23%	04%
Only Solution-oriented	3	08%	08%	20%	25%	13%	18%	08%
Total	25	08%	09%	21%	17%	16%	24%	05%

Note. PD: Problem Detection, PA: Problem Analysis, SS: Solution Suggestion, SEV: Solution Evaluation, SC: Solution Confirmation, GR: Group Regulation, and ST: Strategy.

The quality of solutions was compared in consideration of the combinations. As Figure 1 illustrates, when one or two solution-oriented students collaborated to solve the problems, students submitted better solutions than when only problem-oriented students collaborated, $t(15.16) = 3.93$, $p = .001$.

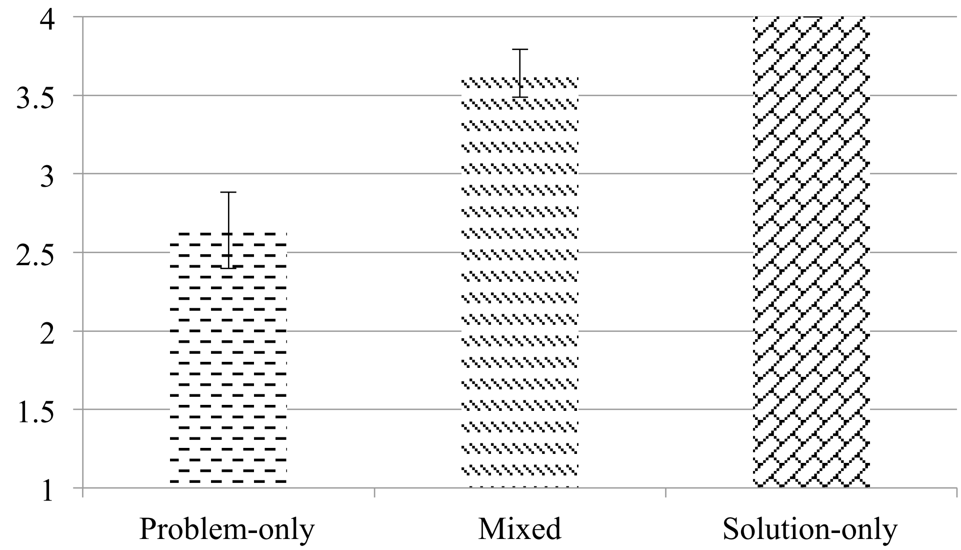

Figure 1. Mean scores of solutions categorized according to the combination of individuals

Note. All solution-only combinations received full credit for all of their solutions.

One can assume that the differences between the solutions might be due to the ability of the students rather than their problem-solving behaviors. Considering that possibility, we examined students' programming knowledge in the middle and at the end of the problem-solving tasks (see Figure 2). Until the third problem-solving task, we did not find a significant difference between the students in terms of their domain knowledge (problem-oriented students: $M = 7.73$, $SD = 1.39$; solution-oriented students: $M = 7.63$, $SD = 1.50$). However, after competing all of the problem-solving tasks, we observed a significant learning gain from the solution-oriented students but not from the problem-oriented students (problem-oriented students: $M = 7.56$, $SD = 1.45$; solution-oriented students: $M = 9.13$, $SD = .63$). The results reject the notion that a student's prior knowledge might affect the quality of their solutions, but support the argument that a student's problem-solving behaviors that focused on the evaluation of solutions affected the solution quality, and resulted in their learning gain.

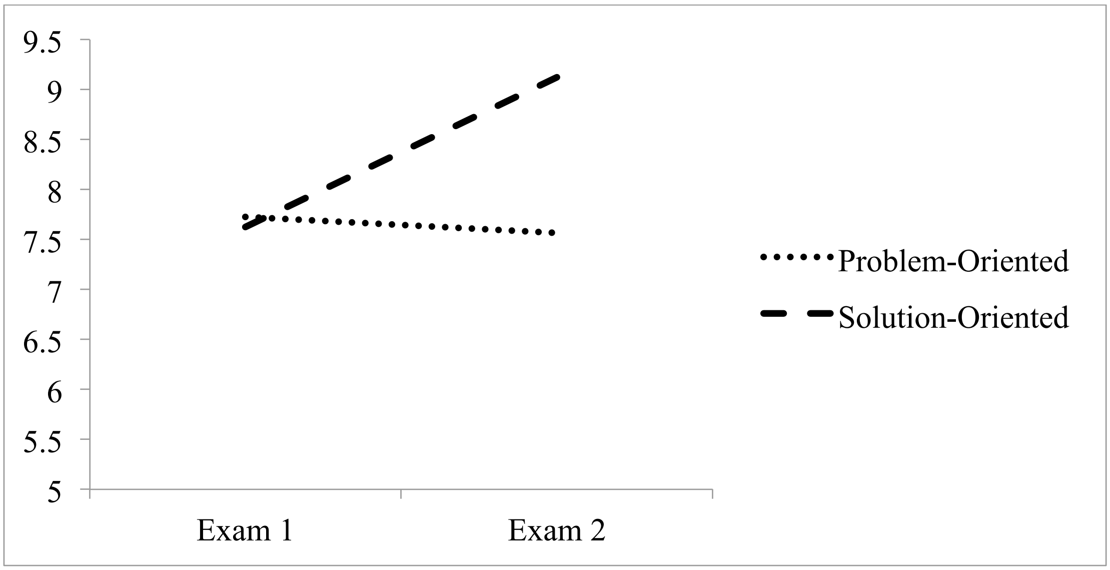

Figure 2. Assessment of students' domain knowledge at two different points of time (after the third and final problem-solving tasks).

Case Analysis on Interactions

In order to understand the relation between the quality of the solution and the problem-solving behaviors, and especially the problem analysis and solution evaluation, we examined episodes within the problem-solving process.

Solution-oriented interactions. The following episodes illustrated how two solution-oriented students analyzed a problem, found a solution and evaluated it before they confirmed the solution. The episodes particularly revealed that the solution-oriented students explicitly evaluated their solutions and shared common ground with their partner.

In the first episode, it seemed the two students understood the problem quite easily and pointed out the issue clearly. After finding the solution, they explained their rationale for the solution to one another, which ensured the quality of solution in this case.

Episode 1

Student	Interaction [*sic*]	Code
Student_A	that makes $i odd and $i is defind by $mod	PA
Student_A	Soooo $mod == 1	SS
Student_B	Okay... I agree with that too because the % means divide right	SEV
Student_A	so if you get 1 its odd and if you don't it's even	SEV
Student_B	And a double == because otherwise it won't work... I learned that the hard way haha	SEV

The following episode illustrates the problem-solving process that another pair of solution-oriented students faced where a problem was not solved easily. In this case, to solve the problem the students needed to write a section of the program code that was left blank. Although they understood the problem and they conceptually knew what was required, they were not able to find a working solution in that situation. Instead they continuously evaluated their solutions and shared their rationale with each other. The noticeable interactions were that they kept explaining their alternative solutions and elaborating on their reasoning together during the problem-solving process.

Episode 2

Student	Interaction [*sic*]	Code
Student_C	i tried putting another $-GET and inputing gender and then gender m but it did not work	SEV
	…	
Student_C	i kinda have an idea i put $_GET["gender"] in each phpcode spot, and it comes up as male, if you put ones a gender f, it comes	SEV

	up female, …	
Student_B	I might be a little confused then because mine comes up as an error	SEV
	…	
Student_C	i have it so its stable, we just need the code that accepts when i click male or female and it registers it	PA
Student_B	the boxes come up right and everything when I try it but there's no isset on that example so maybe it changes when that's involved	PA

Ineffective Problem Analysis. The following episodes illustrate the reasons why problem-oriented students analyzed problems so intensively without benefiting from it. In the first episode, they did not pinpoint the location of problem and discussed the difference between using the double and single quotation which was not related to the real problem. Thus the problem analysis was not helpful to them in narrowing down the problem.

Episode 3

Student	Interaction [*sic*]	Code
Student_D	One thing I noticed do you remember when he said about....umm... the… one quote versus double quotation part?	PD
Student_E	Yeah… but he did that when were in the class too...	PA
Student_D	OK	
Student_E	There was a problem when there was like an apostrophe, and the...	PA

Episode 4 also describes the ineffective problem analysis process between the problem-oriented students. They were not able to figure out which problem caused the error and checked the problematic codes line by line.

Episode 4

Student	Interaction [*sic*]	Code
Student_G	$greeting1 needs quotation marks around the statement	PD
Student_F	I think the single quotations work, that's what we did in class, I'm not sure why though	PA
Student_G	Oh all right I guess both work then. Hmm I can't figure out what's wrong yet	GR
Student_F	Yeah, It's probably something inside of the if then else statements	PD
Student_G	Yea that's what I figure. Well the symbol being used is greater than or equal to I know that much haha	PA

From the episodes, we found that the frequent problem analysis behaviors represented students' insufficient understanding of the problem: conditional statement. Although there was one syntax error causing the problem, they weren't able to find it, so they checked other parts (incorrect PD) ineffectively. Obviously they did not discuss the structure of the conditional statements (ineffective PA) which could have guided them to the location of the syntax error.

Helpful interactions between students. In the following episode, a solution-oriented student explained his problem-solving process to his partner (problem-oriented student). We paid attention to the solution evaluation carried out by the problem-oriented student. In this case, the solution-oriented student suggested an incorrect solution and his partner simply agreed with it (SC) without further discussion. However, both students realized that the solution did not work and tried to figure it out. During the process, the solution-oriented student kept explaining his reasoning process and the results of modification to his partner (SEV), which enhanced their mutual understanding at the end.

Episode 5

Student	Interaction [*sic*]	Code
Student_C	so it would display if the number is odd or even it said "the number is odd" but I am not sure if that is right	SEV
Student_H	yes, I was about to tell you .. :) I go over the power point from week 8. I think you are right	SC
	…	
Student_C	if i put TellNum(3) it says it is even but if I put Tell Num(2) it says even hahaha ok let me tweak.	SEV
	…	
Student_H	:) u did all the work. thank you for making me understand clearly :)	No code

In this study, students did not demonstrate this type of helpful interaction often. More frequently, the students accepted their partner's suggestion without further discussion when they were not confident in themselves, which did not serve to elicit an explanation from their partner, but rather a hasty agreement. This episode, however, showed that the solution-oriented student's voluntarily explanation enabled him to find the correct solution as well as to educate his partner.

Discussion

The purpose of this study was to examine the types of interactions during collaborative problem solving in an online learning environment. Specifically, our research questions included the investigation of the interaction types including individual student's interaction behaviors, and their impact on the solution quality and learning outcomes. We were especially interested in the process of understanding problems and validating solutions. Regarding the interaction types, we were able to categorize the students' interaction into two types: solution-oriented vs. problem-oriented, on the basis of their interaction patterns. As named, the solution-oriented students were more active in evaluating solutions and trying to find correct solutions, whereas the problem-oriented students were less active in evaluating solutions and put more attention toward understanding problems. Results revealed that the more the students evaluated their potential solutions, the better were the solutions they suggested. On the contrary, when students struggled more with understanding the problems, the less likely it was they found correct solutions. Interestingly, we did not find any difference in their domain knowledge until the middle of the experiment. However, the solution-oriented students gained more domain knowledge as compared to the problem-oriented students at the end. Considering the combination of students, when working with at least one solution-oriented student as opposed to only problem-oriented students, the students found better solutions. This indicates that a solution-oriented student would lead the problem-solving process toward a solution evaluation and this interaction had an influence on the solution quality. It also suggests that more frequent interactions involving problem analysis implied insufficient understanding about the problem, and this did not effectively guide them to a correct solution.

Beneficial Interaction for Problem Solving

The results of this study are consistent with previous studies stressing the importance of peer interactions in a problem-solving process (Cooke & Szumal, 1994; Liu & Tsai, 2008; Roschelle & Teasley, 1995). As Barron (2003) suggested, the success of collaboration heavily relies on the participant's ability and motivation to maintain a shared problem-solving space. In her study, less successful collaboration groups rejected or ignored a partner's proposals while the more successful groups elaborated on proposals by discussing or accepting. The current study extended the findings by examining the effect of elaboration during different problem-solving phases: understanding problems and evaluating solutions. While elaboration on the solution phase was beneficial to learning, elaboration on the problem phases were not, and even brought about a negative effect on learning. It should be noted that the result does not suggest the needlessness of understanding a problem but rather emphasizes the necessity for instructional intervention to facilitate the process. This study does not reveal the reason why many students (8 vs. 4) paid more attention to understanding problems as opposed to evaluating solutions. However, it was certain that their interactions in trying to understand problems were not so beneficial to developing correct solutions. Further study is necessary to disclose the reason and suggest instructional interventions.

Previous studies suggested that collaborative learning is more beneficial to novices when they collaborate with expert students (Webb, Nemer, Chizhik, & Sugrue, 1998). When combining students with different levels of competence, less able students are able to observe the more able students' problem-solving performance, and especially their strategy, and practice it themselves in their individual task (e.g., Azmitia, 1988). However, it is also possible that the more competent students could regress when collaborating with less competent students (Tudge, 1992). As Tudge (1992) suggested, collaboration with peers having different levels of competence can cause the improvement or regression of learning.

The current study classified students on the basis of their problem-solving patterns rather than their domain knowledge. It is noteworthy that students who explicitly explained their solutions to their partners (solution-oriented) were able to lead the group interactions toward a more fruitful situation. And as many studies suggested, the explicit elaboration process in regards to the solutions would also positively affect their knowledge gain (Bielaczyc, Pirolli, &

Brown, 1995; Chi, de Leeuw, Chiu, & La Vancher, 1994).

References

Azmitia, M. (1988). Peer interaction and problem solving: When are two heads better than one? *Child Development, 59*(1), 87-96. doi:10.2307/1130391

Barron, B. (2003). When Smart Groups Fail. *Journal of the Learning Sciences, 12*(3), 307-359. doi:10.1207/S15327809JLS1203_1

Bielaczyc, K., Pirolli, P. L., & Brown, A. L. (1995). Training in Self-Explanation and Self-Regulation Strategies: Investigating the Effects of Knowledge Acquisition Activities on Problem Solving. *Cognition and Instruction, 13*(2), 221-252. doi:10.1207/s1532690xci1302_3

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Brindley, J., Blaschke, L. M., & Walti, C. (2009). Creating Effective Collaborative Learning Groups in an Online Environment. *2009, 10*(3). doi:10.19173/irrodl.v10i3.675

Chi, M. T. H., de Leeuw, N., Chiu, M.-H., & La Vancher, C. (1994). Eliciting Self-Explanations Improves Understanding. *Cognitive Science, 18*, 439-477. doi:10.1207/s15516709cog1803_3

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and Representation of Physics Problems by Experts and Novices. *Cognitive Science, 5*(2), 121-152. doi:10.1207/s15516709cog0502_2

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in Problem Solving. In R. Sternberg (Ed.), *Advances in the Psychology of Human Intelligence* (pp. 1–75). Hillsdale, NJ: Erlbaum.

Cooke, R. A., & Szumal, J. L. (1994). The Impact of Group Interaction Styles on Problem-

Solving Effectiveness. *The Journal of Applied Behavioral Science, 30*(4), 415-437. doi:10.1177/0021886394304005

Dehler, J., Bodemer, D., Buder, J., & Hesse, F. W. (2011). Guiding knowledge communication in CSCL via group knowledge awareness. *Computers in Human Behavior, 27*(3), 1068-1078. doi:10.1016/j.chb.2010.05.018

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving Students' Learning With Effective Learning Techniques: Promising Directions From Cognitive and Educational Psychology. *Psychological Science in the Public Interest, 14*(1), 4-58. doi:10.1177/1529100612453266

Ge, X., & Land, S. M. (2003). Scaffolding students' problem-solving processes in an ill-structured task using question prompts and peer interactions. *Educational Technology Research and Development, 51*(1), 21-38. doi:10.1007/BF02504515

Hayes, J. R. (1989). *The complete problem solver* (2nd ed.). Hillsdale, NJ: Erlbaum.

Hesse, F., Care, E., Buder, J., Sassenberg, K., & Griffin, P. (2015). A Framework for Teachable Collaborative Problem Solving Skills. In P. Griffin & E. Care (Eds.), *Assessment and Teaching of 21st Century Skills: Methods and Approach* (pp. 37-56). Dordrecht: Springer Netherlands.

Hmelo-Silver, C. E. (2004). Problem-Based Learning: What and How Do Students Learn? *Educational Psychology Review, 16*(3), 235-266. doi:10.1023/B:EDPR.0000034022.16470.f3

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85. doi:10.1007/BF02300500

Jonassen, D. H., & Kim, B. (2010). Arguing to learn and learning to argue: design justifications and guidelines. *Educational Technology Research and Development, 58*(4), 439-457. doi:10.1007/s11423-009-9143-8

Jonassen, D. H., & Kwon, H. I. (2001). Communication Patterns in Computer Mediated versus Face-to-Face Group Problem Solving. *Educational Technology Research and Development, 49*(1), 35-51. doi:10.2307/30220298

Kapa, E. (2001). A Metacognitive Support during the Process of Problem Solving in a Computerized Environment. *Educational Studies in Mathematics, 47*(3), 317-336. doi:10.1023/A:1015124013119

Kapur, M., & Kinzer, C. K. (2007). Examining the effect of problem type in a synchronous computer-supported collaborative learning (CSCL) environment. *Educational Technology Research and Development, 55*(5), 439-459. doi:10.1007/s11423-007-9045-6

Kerr, N., & Bruun, S. (1983). Dispensability of member effort and group motivation losses: Free-rider effects. *Journal of Personality and Social Psychology, 44*(1), 78-94. doi:10.1037/0022-3514.44.1.78

Krawec, J. L. (2014). Problem Representation and Mathematical Problem Solving of Students of Varying Math Ability. *Journal of Learning Disabilities, 47*(2), 103-115. doi:doi:10.1177/0022219412436976

Kreijns, K., Kirschner, P. A., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: a review of the research. *Computers in Human Behavior, 19*(3), 335-353. doi:Doi: 10.1016/s0747-5632(02)00057-2

Kwon, K., Hong, R., & Laffey, J. M. (2013). The educational impact of metacognitive group coordination in computer-supported collaborative learning. *Computers in Human*

Behavior, 29(4), 1271-1281. doi:10.1016/j.chb.2013.01.003

Lazakidou, G., & Retalis, S. (2010). Using computer supported collaborative learning strategies for helping students acquire self-regulated problem-solving skills in mathematics. *Computers & Education, 54*(1), 3-13. doi:10.1016/j.compedu.2009.02.020

Liu, C.-C., & Tsai, C.-C. (2008). An analysis of peer interaction patterns as discoursed by on-line small group problem-solving activity. *Computers & Education, 50*(3), 627-639. doi:10.1016/j.compedu.2006.07.002

Phielix, C., Prins, F. J., Kirschner, P. A., Erkens, G., & Jaspers, J. (2011). Group awareness of social and cognitive performance in a CSCL environment: Effects of a peer feedback and reflection tool. *Computers in Human Behavior, 27*(3), 1087-1102. doi:10.1016/j.chb.2010.06.024

Poole, M. S., & Holmes, M. E. (1995). Decision Development in Computer-Assisted Group Decision Making. *Human Communication Research, 22*(1), 90-127. doi:10.1111/j.1468-2958.1995.tb00363.x

Raes, A., Schellens, T., De Wever, B., & Vanderhoven, E. (2012). Scaffolding information problem solving in web-based collaborative inquiry learning. *Computers & Education, 59*(1), 82-94. doi:10.1016/j.compedu.2011.11.010

Roschelle, J., & Teasley, S. (1995). The Construction of Shared Knowledge in Collaborative Problem Solving. In C. O'Malley (Ed.), *Computer Supported Collaborative Learning* (Vol. 128, pp. 69-97): Springer Berlin Heidelberg.

Salomon, G., & Globerson, T. (1989). When teams do not function the way they ought to? *International Journal of Educational Research, 13*(1), 89-99. doi:10.1016/0883-0355(89)90018-9

Schoenfeld, A. H. (1992). Learning to Think Mathematically: Problem Solving, Metacognition, and Sense-Making in Mathematics. In D. Grouws (Ed.), *Handbook of Research on Mathematics*. New York: MacMillan.

Simon, H. A. (1978). Information-processing theory of human problem solving. In W. Estes (Ed.), *Handbook of learning and cognitive processes* (Vol. 5, pp. 271-295). Hillsdale, NJ: Lawrence Erlbaum Associates.

Simon, H. A., & Hayes, J. R. (1976). The understanding process: Problem isomorphs. *Cognitive Psychology, 8*(2), 165-190. doi:10.1016/0010-0285(76)90022-0

Suthers, D. D. (2006). Technology affordances for intersubjective meaning making: A research agenda for CSCL. *International Journal of Computer-Supported Collaborative Learning, 1*(3), 315-337. doi:10.1007/s11412-006-9660-y

Tausczik, Y. R., Kittur, A., & Kraut, R. E. (2014). *Collaborative problem solving: a study of MathOverflow*. Paper presented at the Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing, Baltimore, Maryland, USA.

Tudge, J. R. H. (1992). Processes and consequences of peer collaboration: A Vygotskian analysis. *Child Development, 63*(6), 1364-1379. doi:10.1111/j.1467-8624.1992.tb01701.x

Webb, N. M. (1982). Peer Interaction and Learning in Cooperative Small Groups. *Journal of Educational Psychology, 74*(5), 642-655. doi:10.1037/0022-0663.74.5.642

Webb, N. M., & Mastergeorge, A. M. (2003). The Development of Students' Helping Behavior and Learning n Peer-Directed Small Groups. *Cognition & Instruction, 21*(4), 361-428. doi:10.1207/s1532690xci2104_2

Webb, N. M., Nemer, K. M., Chizhik, A. W., & Sugrue, B. (1998). Equity Issues in Collaborative Group Assessment: Group Composition and Performance. *American*

Educational Research Journal, 35(4), 607-651. doi:doi:10.3102/00028312035004607