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on a Computer-Based Collaborative
Problem-Solving Task**

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ROLE OF TASK-SPECIFIC ADAPTED FEEDBACK ON A COMPUTER-BASED COLLABORATIVE PROBLEM-SOLVING TASK

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Abstract

Collaborative problem solving and collaborative skills are considered necessary skills for success in today's world. Collaborative problem solving is defined as problem solving activities that involve interactions among a group of individuals. Large-scale and small-scale assessment programs increasingly use collaborative group tasks in which students work together to solve problems or to accomplish projects.

This study attempts to research the role of feedback on a computer-based collaborative problem solving task by extending Hsieh and O'Neil's (2002) computer-based collaborative knowledge mapping study. In their study, groups of students searched a web environment of information to improve a knowledge map. Various types of feedback were investigated. They found that searching has a negative relationship with group outcome (knowledge map scores). By teaching searching and by providing different types of feedback, this study explores the effects of students' teamwork and problem solving processes on students' knowledge mapping performance. Moreover, the effects of two types of feedback (adapted knowledge of response feedback and task-specific adapted knowledge of response feedback) were also investigated.

One hundred and twenty college students (60 groups) participated in the main study. The students were randomly assigned either to be a group leader whose responsibility was to construct the map or to be a group searcher whose responsibility was to help the leader construct the map by seeking information and accessing feedback from the Web environment. Results showed that task-specific adapted knowledge of response feedback was significantly more beneficial to group outcome than adapted knowledge of response feedback. In addition, as predicted, for the problem solving process, information seeking including request of feedback, browsing, searching for information and searching using Boolean operators were all significantly related to group outcome for both groups.

Lastly, this study confirmed that computer-based performance assessment in collaborative problem solving was effective. The collaboration between team members and individual students' problem solving processes and strategies were effectively recorded by the computers. In addition, the use of computers to assess and report group interaction and students' thinking processes was proven to be more inexpensive and less time consuming than other alternatives.

Introduction

Many research studies on collaborative problem solving have shown a positive effect on students' cognitive improvement (e.g., Arts, Gijsselaers, & Segers, 2002). Recently, computer networks and simulations have been used and proven effective as an assessment tool to measure collaboration skills and problem-solving skills (e.g., Hsieh & O'Neil, 2002). Another influence brought about by advances in computer technology is the new emphasis on the skills needed for electronic information seeking and processing (Covington, 1998). However, many students and teachers alike still lack basic information technology knowledge and skills (Smith & Broom, 2003). Current curriculum, instruction, and assessment do not adequately make use of the capabilities of today's networked information systems. Research has shown that expert searchers locate information faster and use more search logic, such as Boolean operators, in their queries than novice searchers (Lazonder, 2000). Thus research has pointed to a need for training on Boolean search strategies, and a few studies have also demonstrated its effectiveness. However, in Hsieh and O'Neil's study, searching was unexpectedly negatively related to performance on a team knowledge mapping task.

By combining Hsieh and O'Neil's (2002) methodological approach with instruction in search strategies, this study investigated student collaborative problem-solving and team processes on a computer-based knowledge mapping team task with special attention to the effectiveness of feedback. In Hsieh and O'Neil's study, two levels of feedback, adapted feedback and knowledge of response feedback, were compared. Knowledge of response feedback is feedback that informs the learner whether the answer is correct. Adapted feedback was designed in computer-based instruction with attention to customizing feedback for the user's needs rather than providing just one fixed form of feedback. They demonstrated that adapted feedback teams outperformed knowledge of response feedback teams. Continuing in the same fashion, the current study compared two levels of adapted feedback—adapted feedback and task-specific adapted feedback.

The measurement of teamwork processes and problem-solving processes in this study was based on the model developed by the National Center for Research on Evaluation, Standards, and Student Testing (CRESST). The teamwork model consists of six teamwork skills: "(a) adaptability, (b) coordination, (c) decision making, (d) interpersonal, (e) leadership, and (f) communication (O'Neil, Chung, & Brown, 1997, p. 413). The problem-solving model consists of three sub-elements: (a) content understanding, (b) problem-solving strategies, and (c) self-regulation.

In the current study, content understanding was measured by a knowledge map created with and recorded by computer software. A knowledge map is a graphical representation consisting of nodes and links. Nodes represent terms (standing for a concept) in the domain of knowledge. Links represent the relationships between nodes. A proposition is the combination of two nodes joined by a link.

Hsieh and O'Neil (2002) used a simulated Internet Web to evaluate student collaborative problem-solving strategies and outcomes in a computer-based knowledge mapping environment. They successfully showed that adapted feedback was more effective in improving students' performance than knowledge of response feedback. The current study used the same simulated Internet Web space, in which students searched to find information to improve their knowledge maps, and the same simulation also provided students with feedback on their maps.

In the literature, feedback was regarded as an important resource to assist the learning process. Hsieh and O'Neil (2002) demonstrated that feedback access was positively related to outcome performance. However, even though their feedback provided participants with a direction as to "what" area to improve on their knowledge map, it did not provide practical tips on "how" to improve the map. The present study argued that if search tips were provided in the feedback, students would become more effective and efficient in locating the information and in turn improve the overall result of their map. Therefore, we modified Hsieh and O'Neil's original task by providing examples of how to use Boolean operators in addition to information on the area(s) into which participants should put more effort.

Because feedback with search tips was provided, participants in the current study were expected to perform better than Hsieh and O'Neil's (2002) participants in general. In addition, increased use of Boolean operators when doing the simulated Web search was expected.

There were four hypotheses in this study.

Hypothesis 1: Students will perform better on the environmental science knowledge mapping task if they receive task-specific adapted feedback than if they receive adapted feedback.

Hypothesis 2: Students who receive task-specific adapted feedback will be more likely to use decision-making and leadership team processes than students who receive adapted feedback.

Hypothesis 3: Information seeking will have positive effects on team outcome in environmental science knowledge mapping.

3.1 Browsing and searching will be positively related to team outcome.

3.2 The number of requests for feedback will be positively related to team outcome.

Hypothesis 4: Searching using Boolean operators will have positive effects on students' problem-solving strategies and team outcome on the knowledge mapping task.

4.1 The more frequently Boolean operators are used, the higher the map score on the knowledge map.

4.2 The task-specific adapted feedback team will use Boolean operators more frequently in their searching than the adapted feedback team.

Method

Participants

Participates were 120 college students (60 dyads), 18 years of age or older.

Networked Knowledge Mapping System

The mapping system was based on the networked knowledge mapping system developed by Schacter, Herl, Chung, Dennis, and O'Neil (1999) and furthered modified by Hsieh and O'Neil (2002). Using this system, teams of two participants (dyads) created a knowledge map on environmental science by exchanging messages in a collaborative environment and by searching for relevant information in a simulated World Wide Web environment. The participants in a dyad were randomly assigned to the role of leader or searcher. The leader was solely responsible for creating the

knowledge map, and the searcher was solely responsible for accessing the simulated World Wide Web to find information and to request feedback.

The knowledge map concepts were 18 predefined important concepts identified by content experts: atmosphere, bacteria, carbon dioxide, climate, consumer, decomposition, evaporation, food chain, greenhouse gases, nutrients, oceans, oxygen, photosynthesis, producer, respiration, sunlight, waste, and water cycle. The links for the knowledge map were also predefined by content experts: CAUSES, INFLUENCES, PART OF, PRODUCES, REQUIRES, USED FOR, and USES. There were altogether 37 predefined messages with 37 corresponding buttons. When a participant clicked on a button, the corresponding message was sent instantly to both team members' computers. The simulated World Wide Web environment contained more than 200 Web pages with approximately 500 images and diagrams about environmental science.

Feedback

The searcher was allowed to access feedback to find out how well his or her team was performing. Feedback was provided in one of two categories: adapted feedback and task-specific adapted feedback; both were based on comparing students' knowledge map performance to that of experts'. Adapted feedback in the present study was identical with Hsieh and O'Neil's (2002) feedback condition. It pointed out concepts that needed improvement. For example, as can be seen in Figure 1, "atmosphere" needed a lot of improvement according to the feedback.

Your map has been scored against an expert's map in environmental science. The feedback tells you:

- How much you need to improve each concept in your map (i.e., A lot, Some, A little)

Use this feedback to help you search to improve your map.

A Lot	Some	A Little
atmosphere, carbon dioxide, respiration, evaporation, sunlight, water cycle, oceans, bacteria greenhouse gases	food chain, decomposition, consumer, producer	photosynthesis, oxygen, waste, climate

Improvement: You have improved the "food chain" from needing "A lot of improvement" to "Some improvement" category.

Strategy: It is most useful to investigate information for the "A lot" and "Some" categories rather than the "A little" category. For example, improving "atmosphere" or "climate" first rather than "evaporation."

Figure 1. Example of adapted feedback in Hsieh and O'Neil's (2002) study.

Task-specific adapted feedback, used in the current study, included the information contained in adapted feedback and Boolean search strategy tips. Figure 2 shows an example of feedback provided in the present study. Search tips were adapted from the Firstsearch help guide at <http://newfirstsearch.oclc.org/>

As seen in Figure 2, the feedback provided participants a direction as to what area to improve for search and task performance, and also how to improve the performance. It should be noted that the search tips were task-specific adaptive knowledge of results response feedback to help teams to improve their searches.

Your map has been scored against an expert's map in environmental science. The feedback tells you:

How much you need to improve each concept in your map (i.e., A lot, Some, A little).

Use this feedback to help you search to improve your map

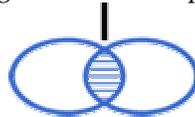
A Lot	Some	A Little
atmosphere, carbon dioxide, respiration, evaporation, sunlight, water cycle, oceans, bacteria greenhouse gases	food chain, decomposition, consumer, producer	photosynthesis, oxygen, waste, climate

Improvement: You have improved the "food chain" from needing "A lot of improvement" to "Some improvement" category.

General Strategy: It is most useful to investigate information for the "A lot" and "Some" categories rather than the "A little" category. For example, improving "atmosphere" or "climate" first rather than "evaporation".

Search strategy 1: Use the Boolean operators AND to combine search terms when you need to expand or narrow a search. AND retrieves only records that contain all search terms. Use this operator to narrow or limit a search.

oxygen AND atmosphere



If you type: oxygen AND atmosphere

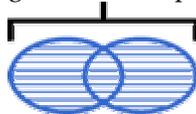
It searches for: Only records containing both oxygen and atmosphere

If you type: oxygen AND atmosphere AND carbon dioxide

It searches for: Only records containing all three search terms—oxygen, and atmosphere, and carbon dioxide

Search strategy 2: If using the Boolean operator AND ends up with no relevant pages found. Use the Boolean operator OR to retrieve all records that contain one or both of the search terms. Use this operator to expand a search.

oxygen OR atmosphere



If you type: Oxygen OR atmosphere

It searches for: Records containing oxygen, records containing atmosphere, and records containing both

Figure 2. Example of task-specific adapted feedback in the present study.

Measures

Team Outcome Measure

Team outcome measures were computed by comparing the semantic content score of a team's knowledge map to that of a set of four experts' maps (Schacter et al., 1999). The following description shows how these outcomes were scored. First, the semantic score was based on the semantic propositions in experts' knowledge maps and was calculated by categorized map scoring (Herl, O'Neil, Chung, & Schacter, 1999). Using this method, all seven links were categorized into four classifications. CAUSES and INFLUENCES were classified as the "casual" category and marked as String 1. REQUIRES, USED FOR, and USES were classified as the "conditional" category and marked as String 2. PART OF and PRODUCES, the remaining two links, were classified individually and marked as Strings 3 and 4 respectively. Every proposition in a student map was compared against each proposition in the four experts' maps using Strings 1–4. One match was scored as one point. The average score across all four experts was the semantic score of the map. For example, if a student team made a proposition such as "Oceans PART OF Water cycle," this proposition would be first categorized into "Oceans 3 Water cycle" and then compared with the four experts' propositions. A score of 1 means this proposition was the same as a proposition in the map of an expert. A score of zero means this proposition was not the same as any of the experts' propositions.

Teamwork Process Measures

Teamwork process scores were calculated by adding the number of messages both members in a team sent from each teamwork process category. That is, if a team leader sent 7 messages from the adaptability category, then that person's individual-level adaptability score was 7. If both the leader and the searcher in a team each sent 7 messages from the adaptability category, the team-level adaptability score was 14.

Information Seeking and Feedback Behavior Measures

Information seeking and feedback behavior were measured by three activities: browsing, searching, and requesting feedback. Browsing was measured by how many times a searcher selected Web pages or clicked on any hypertext within the Web pages. Each time a searcher selected a page or clicked on any hypertext, a point was added. For searching, one point was awarded for simple searches. For example, when a searcher

typed “oxygen” as the search string, one point was awarded. An additional point was awarded if the search used Boolean search strategies. For example, “oxygen AND sunlight” would be counted as two points: one for a simple search and one for using the Boolean operator AND. The score for feedback request was calculated as the number of times the team requested feedback.

Results

Teamwork Process Measure

Table 1 presents teamwork process measure frequency counts for all six teamwork processes. In general, the reliability of the teamwork process measure was unacceptably low. Alpha reliability ranged from -0.03 (leadership) to 0.48 (interpersonal). Examination of the “Alpha if item deleted” data indicated that deletion of some messages would improve the reliability. After deleting items, the final alpha reliability for these processes ranged from 0.29 for decision making to 0.65 for coordination. Alpha reliability for the other subscales ranged from 0.37 for adaptability, 0.29 for decision making, 0.46 for leadership and 0.48 for communication.

The frequency counts were calculated by adding the number of usage for the individual messages in each teamwork process, after item deletion, and then dividing by the number of teams. In addition, because some team processes had more messages than others, a new metric was created by using a mean. The means in Table 1 were calculated by taking the mean of the frequency count for a category and dividing it by the number of messages left in that category after item deletion. Using adaptability as an example, the mean of 4.80 was divided by 3 , the number of messages left after item deletion; therefore, the final mean was calculated to be 1.60 .

Table 1

Frequency Count of Teamwork Processes: Team Level ($N = 60$)

Teamwork process	No. of messages	M	SD	Min.	Max.
Adaptability	3	1.60	3.26	.00	18.00
Coordination	2	0.50	1.71	.00	8.00
Decision making	4	2.01	7.98	.00	39.00
Interpersonal	5	1.39	5.32	.00	23.00
Leadership	2	0.73	1.78	.00	7.00
Communication	2	0.79	2.22	.00	10.00

Table 2 shows the intercorrelations for the teamwork process variables and the two feedback condition teams. For the adapted feedback team, six significant correlations were found. First, decision making was significantly correlated with adaptability ($r = 0.39, p < 0.05$). In addition, a significant correlation was found between communication and leadership ($r = 0.76, p < 0.01$). Moreover, "all messages sent" significantly correlated with adaptability ($r = 0.47, p < 0.01$), decision making ($r = 0.80, p < 0.01$), and interpersonal ($r = 0.71, p < 0.01$). Since "all messages sent" was calculated as the sum of all messages in the six individual categories, these results were expected. Last, team outcome was negatively correlated with leadership ($r = -0.39, p < 0.05$). This correlation indicates that the greater the number of leadership messages sent, the worse the team outcome was. This result was unexpected.

For the task-specific adapted feedback team, 10 significant correlations were found. First, adaptability was significantly correlated with leadership ($r = 0.37, p < 0.05$) and communication ($r = 0.52, p < 0.01$). Second, coordination was significantly correlated with interpersonal ($r = 0.60, p < 0.01$). Leadership, in addition to being significantly correlated with adaptability, as mentioned above, was also significantly correlated with communication ($r = 0.43, p < 0.05$). These significant relationships indicate that an increase in the number of leadership messages sent resulted in an increase in the number of adaptability messages and communication messages sent, or vice versa, by the task-specific adapted feedback team.

In addition, “all messages sent” was significantly correlated with adaptability ($r = 0.43, p < 0.05$), decision making ($r = 0.59, p < 0.01$), and interpersonal ($r = 0.47, p < 0.01$) processes. Communication ($r = 0.39, p < 0.05$) was significantly correlated with “all messages sent.” Last, team outcome was significantly correlated with interpersonal messages sent and with “all messages sent.” This set of correlations indicates that the greater the number of interpersonal messages sent, the better the team outcome.

Table 2

Intercorrelations for Team-Level Teamwork Process Measures and Team Outcome for the Adapted Feedback Team ($n = 30$) and for the Task-Specific Adapted Feedback Team ($n = 30$)

	1	2	3	4	5	6	7	8
1. Adaptability		0.31	-0.24	0.16	0.37*	0.52**	0.43*	0.16
2. Coordination	0.10		-0.34	0.60**	-0.18	-0.15	0.22	0.21
3. Decision making	0.39*	0.14		-0.18	-0.11	0.00	0.59**	0.12
4. Interpersonal	0.17	0.32	0.34		-0.16	-0.04	0.47**	0.49**
5. Leadership	-0.19	0.03	-0.04	0.02		0.43*	0.13	0.18
6. Communication	-0.09	-0.12	-0.01	-0.02	0.76**		0.39*	0.15
7. All messages sent	0.47**	0.35*	0.80**	0.71**	0.27	0.27		0.48**
8. Outcome performance	0.27	0.08	-0.05	0.33	-0.39*	-0.31	0.06	

Note. Intercorrelations for the adapted feedback team are shown below the diagonal.

* $p < .05$, two-tailed. ** $p < .01$, two-tailed.

Team Outcome Measure

The mean team outcome for the adapted feedback team was 10.96, and for the task-specific adapted feedback team it was 12.96. The mean difference for team outcome for the two feedback treatment teams was statistically significant, $t(29) = 2.09, p = 0.046$.

The maximum possible team outcome score was 23.31. This score was calculated as the average of the four expert map scores. Thus the students in this study demonstrated 51% of the experts' knowledge, whereas the students in Hsieh and O'Neil's (2002) study demonstrated 42% of the experts' knowledge. The mean difference for team outcome in this study and Hsieh and O'Neil's study was statistically significant, $t(59) = 3.75, p = 0.00$. In Hsieh and O'Neil's study, the participants were high school students, whereas in this study, the participants were college students.

Problem-Solving Process Measures

Table 3 presents descriptive statistics for problem-solving variables in this study. As can be seen in Table 3, for the total team ($N = 60$), the mean score for content understanding (knowledge map score) was 10.96. For problem-solving strategies, for the total team, the mean for "browsing" was 88.47, the mean for "searching" was 16.17, the mean for "Boolean operators used" was 4.00, and the mean for feedback was 19.53. A two-tailed t test shows that a significant difference between teams was found for browsing, $t(29) = 2.52, p = .02$, and numbers of Boolean operator used, $t(29) = 2.52, p = 0.02$, both for the task-specific adapted feedback team. No significant difference was found for searching, $t(29) = 0.57, p = 0.58$, or feedback accessing, $t(29) = 0.24, p = 0.82$.

Table 3

Descriptive Statistics for Problem-Solving Variables

Information seeking and feedback behavior	Total (<i>N</i> = 60)		Adapted feedback team (<i>n</i> = 30)		Task-specific adapted feedback team (<i>n</i> = 30)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Content understanding						
Knowledge map score	11.97	3.67	10.96	3.26	12.96	3.84
Problem-solving strategies						
Browsing	113.31	73.79	88.47	54.53	138.17	82.62
Searching	17.15	12.84	16.17	12.61	18.13	13.21
Boolean operators used	5.62	5.06	4.00	3.90	7.23	5.62
Feedback	20.01	15.07	19.53	15.38	20.50	15.01
Self-regulation						
Planning (8 items)	3.14	0.44	3.19	0.45	3.08	0.42
Self-checking (8 items)	3.03	0.50	3.11	0.52	2.93	0.46
Effort (8 items)	3.09	0.47	3.17	0.49	3.01	0.45
Self-efficacy (8 items)	2.93	0.60	3.04	0.61	2.80	0.58

There were many significant correlations found among the problem-solving process measures. As may be seen in Table 4, for the total team ($N = 60$), knowledge map score (content understanding) was significantly related to browsing ($r = 0.40$, $p < 0.01$), searching ($r = 0.43$, $p < 0.01$), Boolean operators used ($r = 0.42$, $p < 0.01$), and feedback accessing ($r = 0.38$, $p < 0.01$). Furthermore, the four problem-solving strategies (browsing, searching, Boolean operators used, and feedback accessing) were correlated to one another significantly. Browsing was significantly related with searching ($r = 0.72$, $p < 0.01$), Boolean operators used ($r = 0.75$, $p < 0.01$), and feedback accessing ($r = 0.74$, $p < 0.01$). Searching was significantly related to Boolean operators used ($r = 0.92$, $p < 0.01$) and feedback accessing ($r = 0.84$, $p < 0.01$). Boolean operators used was significantly related to feedback accessing ($r = 0.79$, $p < 0.01$). As for the four self-regulation measures (planning, self-checking, effort, and self-efficacy), they were all significantly related to one another. However, no significant correlation was found among the four self-

regulation measures (Hong, O’Neil, & Feldon, in press; O’Neil & Herl, 1998) and the three problem-solving strategies. In addition, there was no significant correlation found among the four self-regulation measures and the team outcome.

Table 4

Correlations of Team Outcome and Problem-Solving Variables

Problem-solving variables	Team outcome—knowledge map score		
	Total (<i>N</i> = 60)	Adapted knowledge of response feedback team (<i>n</i> = 30)	Task-specific adapted knowledge of response feedback team (<i>n</i> = 30)
Problem-solving strategies			
Browsing	0.40**	0.36**	0.36**
Searching	0.43**	0.44**	0.40**
Boolean operators used	0.42**	0.41**	0.37**
Feedback	0.38**	0.35**	0.42**
Self-regulation			
Planning	-0.11	-0.08	-0.07
Self-checking	0.05	0.04	0.18
Effort	-0.06	-0.04	0.00
Self-efficacy	-0.12	-0.08	-0.07

p* < .05, two-tailed. *p* < .01, two-tailed.

For the adapted feedback team, knowledge map score (content understanding) was significantly related to browsing ($r = 0.36, p < 0.01$), searching ($r = 0.44, p < 0.01$), Boolean operators used ($r = 0.41, p < 0.001$), and feedback accessing ($r = 0.35, p < 0.01$). There was no significant relationship found between knowledge map score and self-regulation measures (planning, self-checking, effort, and self-efficacy). However, each of the four self-regulation measures was significantly correlated with the other three, and each of the four problem-solving strategies (browsing, searching, Boolean operators used, and feedback accessing) was significantly correlated with the other three. Nevertheless, none of the self-regulation measures were correlated significantly with any of the problem-solving strategies (browsing, searching, Boolean operators used, and feedback accessing).

The significant correlations found for the task-specific adapted feedback team were similar to those found for the adapted feedback team. For the task-specific adapted feedback team, knowledge map score (content understanding) was also significantly related to browsing ($r = 0.36, p < 0.01$), searching ($r = 0.40, p < 0.01$), Boolean operators used ($r = 0.37, p < 0.01$), and feedback accessing ($r = 0.42, p < 0.01$). No significant relationship was found between knowledge map score and self-regulation measures (planning, self-checking, effort, and self-efficacy). Each of the four self-regulation measures significantly correlated with the other three, and each of the four problem-solving strategies significantly correlated with the other three. Nevertheless, none of the self-regulation measures was correlated significantly with any of the problem-solving strategies (browsing, searching, Boolean operators used, and feedback accessing).

In Hsieh and O'Neil's (2002) study, for the adapted feedback team, searching was unexpectedly negatively related to team outcome ($r = -0.40, p < 0.05$). This was not the case in the current study. All four problem-solving strategies were significantly positively related to team outcome (knowledge map score) in both feedback conditions. One difference between the two studies is that searching was explicitly taught in the current study but was not taught in the Hsieh and O'Neil study.

Tests of Hypotheses

For Hypothesis 1, the results indicate that the task-specific adapted feedback team performed significantly better on the knowledge map than the adapted feedback team. A *t* test (two-tailed) on team outcome between the adapted feedback team and the

task-specific adapted feedback team showed a significant difference between the means, $t(29) = 2.09$, $p = 0.046$. As expected, students who received task-specific adapted feedback ($M = 12.96$) performed better than those who received adapted feedback only ($M = 10.96$). Thus Hypothesis 1 was supported.

For Hypothesis 2, the results indicate that students receiving task-specific adapted feedback used approximately the same number of decision-making and leadership messages in their communications as students receiving adapted feedback. The difference between the two teams was not significant for the decision-making team process, $t(29) = 0.31$, $p = 0.76$, or the leadership team process, $t(29) = -1.51$, $p = 0.14$. Thus, Hypothesis 2 was not supported.

For Hypothesis 3, Table 4 shows the correlations between information-seeking variables and team outcome. As expected, browsing was significantly related to team outcome (knowledge map score). In addition, feedback accessing was positively related to team outcome. In other words, the more browsing students did, the higher their team outcome (map score) was. Furthermore, the more feedback students requested, the better their team outcome (map score) was. Thus Hypotheses 3.1 and 3.2 were supported.

For Hypothesis 4, as may be seen in Table 4, significant positive correlations were found for the total team ($N = 60$), $r = 0.42$, $p < 0.01$, the adapted feedback team, $r = .41$, $p < 0.01$, and the task-specific adapted feedback team, $r = 0.37$, $p < 0.01$. Thus, Hypothesis 4.1 was supported.

Also, as shown in Table 3, students in the task-specific adapted feedback team used more Boolean operators than students in the adapted feedback team. A t test (two-tailed) showed the mean difference in number of Boolean operators used between the two feedback teams to be significant, $t(29) = 2.52$, $p = 0.02$. Thus Hypothesis 4.2 was supported.

Discussion

First, results from the study provide evidence indicating that students who received task-specific adapted feedback performed significantly better than students who received adapted feedback. This finding was consistent with several themes in the feedback literature. For example, adapted feedback was suggested by Sales (1993) to customize along one or more dimensions to compensate for the weakness of generic feedback that lacks capacity to communicate with learners. Hsieh and O'Neil's (2002)

study showed that such adapted feedback was better in assisting students in knowledge map construction than knowledge of response feedback. Moreover, Ross and Morrison (1993) defined task-specific feedback as elaboration feedback that concentrated on the current test item. They found task-specific feedback was better than general feedback in assisting learning. Other than Ross and Morrison's study and the current study, there has been no research that investigated task-specific adapted feedback. Our results support the efficacy of such task-specific adapted feedback.

Additionally, in regard to feedback presentation style, Kalyuga, Chandler, and Sweller (2000) found that low-knowledge or inexperienced learners benefited most from feedback combining diagrams with additional text-based information. Foster and Macan (2002) showed that providing information about a process or strategy could optimize learning during practice. In their study, participants who received this type of feedback (called attentional advice) had significantly higher achievement than those receiving no advice at all.

Finally, the results are consistent with a theoretical framework of dynamic testing. According to Grigorenko and Sternberg (1998), "Dynamic testing is a collection of testing designed to quantify not only the products or even the processes of learning but also the potential to learn" (p. 75). In other words, dynamic testing not only provides students with accuracy reports on how they are doing on a test, but also provides them with information on how to improve the quality of their work on the test during the time of the testing. Dynamic testing can do so because it assigns a different role to feedback than the one assigned in traditional static testing. In traditional static testing, feedback about performance is usually not given during the test. In dynamic testing, feedback is given during the test to help assess learning. In this study, the students were considered to be low-prior-knowledge students in environmental sciences. Combining the research findings on feedback and dynamic testing, two types of feedback were created. Adapted feedback was presented in a graphical format with extra text based on general task improvement strategies. Task-specific adapted feedback was presented in a graphical format with extra text based on general task improvement and task-specific strategies. In this study, the feedback was given not after the test but during the test to help students learn. As predicted, the task-specific adapted feedback team performed significantly better than the adapted feedback team. Students who received feedback with task-specific information constructed better knowledge maps than students with no task-specific information. The claim made by dynamic testing, about the role of feedback as a learning strategy to assist students' performance during

the task, was shown to be feasible and successful. Students with task-specific information showed a higher use of the Boolean search strategy than students without that information.

The finding that indicated information searching and use of Boolean search operators was beneficial for team outcome was in line with the search literature. Baker and O'Neil (2003) included use of search engines as one of the requirements of technological fluency. In addition, they listed use of Boolean operators as an example of a cognitive strategy for use in a problem-solving search task. In an observational study of novice users searching information on the World Wide Web, Lazonder (2000) suggested instructing students in search logic such as use of Boolean operators to improve the quality of their searching. The results from the current study support the literature on searching with Boolean operators and training in their use.

In this study, both collaboration between team members and problem-solving processes were effectively measured, administered, scored, and reported by computer. However, the results from this study should not be generalized due to the following limitations. Firstly, the findings should not be applied to other types of teams due to the fact that a dyad is different from other types of teams and team size is an important variable in the teamwork literature. Secondly, the college students assessed in this study were a very restricted population. Lastly, future study can improve by providing stronger evidence on team performance using multiple indicators rather than one single indicator as used in this study.

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