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ABSTRACT

The feasibility of using a computer-based networked collaborative concept mapping system to measure teamwork skills was studied. A concept map is a node-link-node representation of content, where the nodes represent concepts and links represent relationships between connected concepts. Teamwork processes were examined for a group concept mapping activity using networked computers and HyperCard software developed for the study. Two pilot studies investigated the feasibility of the approach, and one of these is reported in this study. Thirty 9th graders worked together in the first pilot study to create collaborate maps on the computer systems. Results of this study and a second confirmatory study resulted in development of a study with 23 groups of 3 students each from middle schools and high schools. Usable data were recorded for 15 groups (45 participants). Results suggest that the real-time measurement of teamwork skills is feasible and that students using the networked computers were able to create a concept map jointly. The number of concepts used by groups ranged from 7 to 18, and the number of links ranged from 8 to 26. It is suggested, however, that the task involved may be more like a small group task than a "team" task if the purpose of a team is defined as performing a task an individual cannot perform alone. The developed software architecture has been designed to be domain independent and should be useful in other computer-based team environments. (Contains 1 figure, 8 tables, and 20 references.) (SLD)

Use of Networked Collaborative Concept Mapping to Measure Team Processes and Team Outcomes

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In this study we examined the feasibility of using a computer-based, networked collaborative concept mapping system to measure teamwork skills. A particularly novel feature of our work is that we are refining an approach that employs networked computers to capture and measure – in real-time – team processes for individual students and teams. The current work, together with our past efforts (e.g., O'Neil, Allred, & Dennis, in-press-a; O'Neil, Chung, & Brown, in press-b), suggests a promising approach toward the development of a real-time measurement system for teamwork skills.

Teamwork Processes

Our work focuses on assessing team processes used by a group of individuals responsible for jointing constructing a concept map. A concept map is a node-link-node representation of content, where nodes represent concepts and links represent relationships between connected concepts (Dansereau, 1995; Jonassen, Beissner, & Yacci, 1993). We are interested in measuring the interaction between team members as they work together to construct a group concept map.

Our definition of *team* is from Tannenbaum, Salas, and Cannon-Bowers' (1996) and Baker and Salas (1992): "... two or more people who interact dynamically, interdependently and adaptively and who share at least some common goals or purpose," and where the team members have built-in dependencies and where each member has well defined roles and positions.

We have drawn on the work of Morgan, Salas, and Glickman (1993), Salas, Dickinson, Converse, and Tannenbaum (1992), Burke, Volpe, Cannon-Bowers, and Salas (1993), and others (O'Neil, Baker, & Kazlauskas, 1992; Webb, 1993; Webb & Palincsar, 1996) to aid our development of teamwork process measures. Morgan et al. provide insight into the nature of teams. In their model of team development, Morgan et al. postulate two tracks of team processes, a taskwork track and a teamwork track. The taskwork track accounts for specific activities unique to the task. Taskwork team skills influence how well a team performs on a particular task (e.g., how well a team of students are able to jointly construct a concept map). Taskwork skills are domain-dependent, task-related activities. The teamwork track or teamwork skills influence how effective an individual member will be as part of a team and are domain-independent. Teamwork skills encompass skills such as adaptability, coordination, cooperation, and communication. Effective teams develop competence along both tracks. Members of effective teams possess basic skills required for the task and know how to coordinate their activities, communicate with each other, and respond effectively to changing conditions.

In the current work we use the taxonomy of teamwork process developed by O'Neil et al. (in press-b). The taxonomy is made up of six processes: (a) adaptability – recognizing problems and responding appropriately, (b) communication – the exchange of clear and accurate information, (c) coordination – organizing team activities to complete a task on time, (d) decision-making – using available information to make decisions, (e) interpersonal – interacting cooperatively with other team members, and (f) leadership – providing structure and direction for the team. Our prior research showed statistically significant positive relationships between decision making and team performance on a negotiation task (final contract offer and quality of agreement), and a significant negative correlation between interpersonal processes and whether an agreement was reached (O'Neil et al., in press-b).

Team processes in a group concept mapping. In this study we examined teamwork processes in the context of a group concept mapping activity, where communication occurred over networked computers. To the best of our knowledge, this has never been done before – we know of no theoretical framework that has been tested using a group concept mapping task. Thus, our expectations about what processes team members invoke are tentative at best.

We view group concept mapping as a weak instance of Tannenbaum et al.'s (1996) definition of a team, particularly in member interdependency and specialized member function. We expect member interdependency to be low given the ease of concept mapping. We have found through pilot testing that elementary school children to graduate students can successfully use our system to construct concept maps. The ease of use of our system and the simplicity of concept mapping means that anyone can carry out the task, which means that there are no specialized skills necessary to carry out the task. Given our typical team scenario of (a) teams comprised of non-experts and (b) one leader and two advisory members (see O'Neil et al., in press-b for a detailed description), and the simplicity of the task, we expect each person on a team (even novices) to be able to perform either role equally well. Finally, we expect concept mapping performance to be essentially knowledge driven. To the extent that teamwork processes emerge, we expect these processes in general to be mediated by the content expertise of team members. Teams with members low in content knowledge are expected to focus primarily on surface features of the task and far less on the substantive part (Chi, Glaser, & Farr, 1988).

Thus, given these characteristics of group concept mapping – easy to use computer system, easy to complete task, content novices – we expect low performance and we do not in general expect to see strong relationships between many of the team processes and concept map performance. The one exception is decision making. Given that concept maps are knowledge dependent, we expect teams that engage in discussion about the content to make reasoned, informed decisions about concepts and their relations, and thus perform better on the concept mapping task.

Measuring Team Processes Within a Networked Environment

Existing approaches to measuring teamwork processes almost exclusively rely on observational methods (Baker & Salas, 1992). For example, behavioral checklists (e.g., Oser, McCallum, Salas, & Morgan, 1989), videotaped and audiotaped observation (e.g., Brannick, Roach, & Salas, 1993), and analysis of think-aloud protocols are the most common techniques to measure teamwork processes. These methods are labor intensive and time-consuming. Observations must be transcribed, coded, and analyzed post hoc. Such techniques offer no opportunity for rapid analysis and reporting of team performance. From an assessment perspective, these methods are unappealing because of the lag between test administration and reporting of test results. Further, these methods are neither practical nor cost-effective in large-scale test settings. Our approach to addressing these limitations is to employ computer-based assessments. Our prior work suggests that this is a feasible and promising approach to assessing teamwork skills (O'Neil et al., in press-b). The work reported here is an extension of our approach to a different domain and a different task.

To measure teamwork skills we use a domain independent taxonomy of teamwork processes to guide the development of a set of domain specific messages. These predefined messages are the sole means for members to communicate with each other, and the messages map on to the teamwork processes (adaptability, coordination, decision making, interpersonal, and leadership). As the team carries out the task the software tracks which messages (and hence which categories) are used by each member. Thus, message usage provides an index of the kinds teamwork processes members are using. We assume that each message in a category is as important as any other message, and thus all messages are equally weighed. This technique provides us with a real-time teamwork assessment system. The assessment can be administered, scored, and reported in real-time.

PILOT STUDIES

Two pilot studies were conducted to assess the feasibility of our approach. The first pilot study was our initial attempt at assessing the functionality of the computer system and determining the kinds of messages participants (in a group) use to construct a concept map. We were interested in feedback from users regarding usage of the system and the task. The second pilot study reflected several major revisions to the system based on the first pilot study, and verified that our technique was feasible (i.e., students could jointly construct concept maps using our system). Only the first pilot study is described here.

Pilot Study 1

Participants and team concept mapping task. 30 ninth grade male and female students were randomly drawn from five 10th-grade classes. All students spoke English as their first language.

We assigned participants to three-person teams where each person had their own computer and the computers were networked together. The scenario we used was one where there was one leader and two members. Only the leader could manipulate the concept map (e.g., adding concepts and links). Non-leaders could only advise by sending messages.

Participants were instructed to jointly construct a concept map on environmental science. One of the reasons we used environmental science as the topic was that it was part of the curriculum; thus, students were presumed to have some familiarity with the subject. We provided the team with 15 terms (atmosphere, bacteria, climate, CO2, decomposition, evaporation, food resources, oxygen, precipitation, respiration, sun light, vegetation, photosynthesis, waste, water) and 9 links (contributes to, causes, leads to, part of, result of, similar to, produced by, influences, type of, prior to).

Leadership passed every 12 minutes (i.e., 1/3 of the task time) among team members to allow each member to control the map once. Teams were given 36 minutes to complete the concept map. The map was scored in real-time by the computer using a scoring algorithm that compared students' maps with an expert's map (Herl, Baker, & Niemi, 1996).

Networked concept mapper. The system was developed on the Macintosh® with HyperCard®. We used the built-in networking capabilities of the operating system (System 7®) and HyperCard® to implement a rudimentary peer-to-peer system. Every member's screen was updated as changes occurred (e.g., someone sending a message, or the leader making changes to the concept map); thus, all computers were synchronized with each other. Communicating between team members occurred via typed messages. To send a message, members typed what they wanted to say in a special message box and then sent the message. The message was dispatched to other members' computers and appeared in the order they were sent. To make changes to the concept map, the leader could add, delete, or move concept map components around the screen. Each time a concept map event occurred, the event was dispatched to other members' computers and their concept maps automatically updated. All typed messages and concept map events were logged by the computer.

Results. All groups participated in the concept mapping task with sustained interest and effort. There was unanimous agreement from all participants and their teachers that the collaborative mapping task was interesting, engaging, and fun. All groups, with only a few minutes of instructions, were able to immediately use the system and engage in the task. All groups were able to construct a map within the allotted time.

Team processes. 798 messages were sent by all groups. All messages were rated by one experimenter. Messages were rated first as on-task or off-task. 557 messages were rated as on-task (74%) and 211 (26%) messages were rated as off-task. On-task was defined as being directly related to constructing a concept map (e.g., "Add evaporation and make a link to water." versus "What was the last good movie you guys saw?"). On-task messages were then categorized into one of the teamwork process categories. Total message usage was: adaptability – 151 messages (26%), coordination – 12 messages (2%), decision making – 80 messages (14%), interpersonal – 15 messages (3%), leadership – 223 messages (38%), and communication – 87 messages (15%). Two additional categories were used to capture messages that reflected errors with using the system (e.g., a message reflecting a typing error, 3 messages, 1%) and a second category to record uncategorizable messages (16 messages, 3%).

Team concept mapping performance. Team performance was measured with concept mapping scores. The concept maps were scored by comparing the group map with an expert map in terms of the content and structure of the map (Herl et al., 1996). Herl et al. reported that this concept mapping scoring approach yielded reliable scores with strong positive correlations with other measures of content knowledge (e.g., essay writing and prior knowledge short answer questions). In this pilot study, the average team content score was 6.4 (SD=2.72, range=2 to 11) out of a possible 38. The average team structure score was .29 (SD=.08, range=.14 to .37) out of a possible 1.0. The scores indicate little content knowledge of these students compared to an expert.

Individual message counts were also scaled by the total number of messages sent by the group. Nonparametric (Spearman) correlations were then examined between the six teamwork processes and the two outcome measures. For the content score, a significant negative correlation was found for communications ($r_S(10)=-.74, p=.007$). The more teams used communication messages, the lower they scored on the content measure. For the structure score, a significant positive correlation was found for decision making ($r_S(10)=.59, p=.02$), and a significant negative correlation for adaptability ($r_S(10)=-.65, p=.02$). The more teams used decision making messages (e.g., "Why oxygen [sic] why not a natural disaster?"), the higher they scored on the structural measure. Conversely, groups that used more adaptability messages (e.g., "What should we link next?") tended to score significantly lower on the structural measure.

These results, while limited in scope, are consistent with our previous findings (O'Neil et al., in press-b). In particular, teams could use predefined messages to communicate with each other, and teams could complete the task. Also, decision making seems to be a key factor in how a group performs. Groups that engaged in higher levels of decision making tended to perform higher on the concept mapping task. Also consistent with O'Neil et al. was that no other significant correlations were found between other group processes and team performance.

MAIN STUDY

Method

Participants

Twenty-three groups (69 participants) were randomly drawn from four middle school and high schools to participate in this study. All students spoke English as their first language. Technical problems resulted in some computers crashing, which resulting in usable data for only 15 groups (45 participants).

Networked Concept Mapping System

Table 1 lists the specifications for our networked concept mapping system. Our system was developed using HyperCard® running on the Macintosh®. The software was designed to be simple and easy to use. Participants sent messages by clicking on numbered buttons. Concepts were added to the concept map via menu selections, and links were created by connecting two concepts and then selecting the desired link from a pop-up menu. Our pilot studies and in-house usability testing showed that participants of various ages (5th graders to graduate students) could be trained to use the system within a few minutes.

Table 1. Domain Specifications Embedded in the Software

General domain specification	This software
Scenario	Create a concept map on environmental science by exchanging messages in a collaborative context
Participants	Student team (3 members)
Concept map terms	Predefined. 18 important ideas 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.
Concept map links	Predefined. 7 important relationships identified by content experts: causes, influences, part of, produces, requires, used for, and uses
Type of learning	Content understanding
Outcome measures	Semantic content scores (stringent and categorized), organizational structure score, number of terms used, number of links used.
Teamwork processes	Adaptability, coordination, decision making, interpersonal, leadership, communication

User Interface. Figure 1 shows the user interface to the system. The display was partitioned into three major sections. The top-fifth was reserved for concept mapping. The lower left of the screen displayed the messages. All messages sent were listed in the order sent by members. Thirty-five numbered buttons were provided to members. Each participant was given a paper handout that listed all messages, and the messages were numbered to correspond to the buttons on the computer screen. To send a message, participants clicked on a button and the corresponding message was sent to everyone's computers. Other information shown on the lower part of the screen was the remaining time for the entire task, and the remaining time as a leader or non-leader. As shown in Figure 1, the remaining time as a leader (i.e., person who controls the map) is two minutes, and the time remaining for the entire task is 32 minutes.

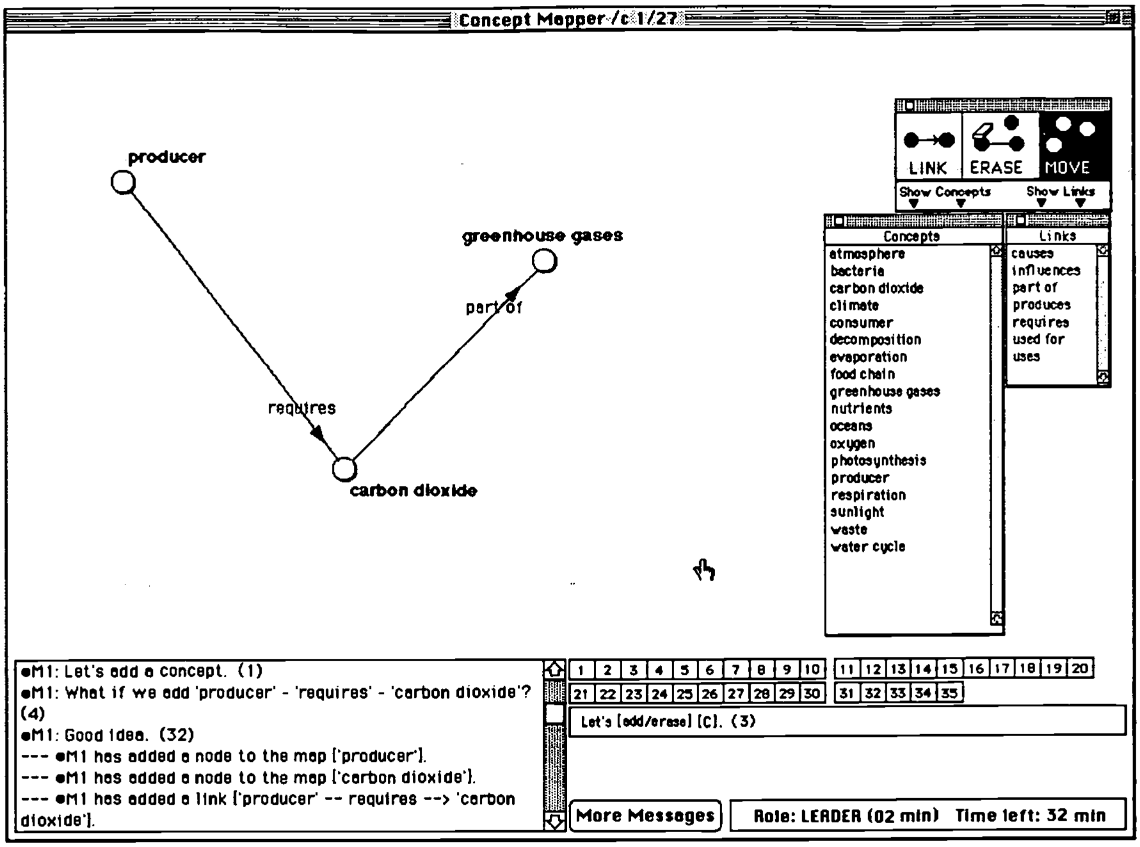

Figure 1. User interface for the system.

Messages. In order to capture team processes in real-time, we provided participants with 37 messages that belonged to one of the five team process categories. Team members used these messages to communicate with each other during the concept mapping task.

Each message belonged to one of the five teamwork process categories (adaptability – 7 messages, coordination – 7 messages, decision making – 6 messages, interpersonal – 7 messages, and leadership – 7 messages). Two messages ("Yes" and "No") were part of the communication category. Another message was provided to signal that a previously sent message was mistakenly sent by the participant. This message was excluded from the message categories. A sample message from each category is given in Table 2.

Table 2. Definitions and example messages for each team process category.

Team process	Definition and example
Adaptability	Recognizing problems and responding appropriately. [*What do you think, M1?* (M1 refers to Member 1 of the team.)]
Coordination	Organizing team activities to complete a task on time. (*We only have 5 minutes left.)*
Decision making	Using available information make decisions. (*What if we add 'carbon dioxide'?)*
Interpersonal	Interacting cooperatively with other team members. (*I need to hear from all of you.)*
Leadership	Providing direction for the team. (*Let's link 'carbon dioxide' to 'producer'.)*
Communication[1]	The clear and accurate exchange of information. (*Yes, No)*

[1]We operationalized communication as the sum of all "Yes" and "No" messages, plus the total of all other messages, less the number of error messages.

Measures

The measures used in this study focused on team skills within a group concept mapping context. Performance was measured by how well the team's concept map compared to experts' maps. Process measures included team processes (as measured by message usage). Each measure is described below.

Team outcome measures. Our team outcome measures were computed by comparing a teams' concept map against a set of experts (Herl et al., 1996). Two semantic content scores, a concept map structure score, and the number of concepts and links in the group map were used as outcome measures.

To derive semantic content scores, two different scoring criteria were used. The first technique used a stringent criteria. Every proposition in the group's map (i.e., concept-link-concept tuple) was compared against all propositions in an expert's map. A point was awarded for each match. This comparison was done against four expert maps, and the group's semantic content score was the average score. A less stringent score was computed using link categories. Links in both the group and expert maps were categorized into the abstract categories. After this recoding, the score was recomputed. The effect of the categorizing specific links into more abstract categories is to remove subtle differences between links (e.g., "causes" and "influenced" were classified as belonging to the 'causal' category). An organizational structure score was computed that measured the similarity in network characteristics between a group's map and the experts' maps. Herl et al. (1996) gives a complete discussion of all scoring algorithms.

Procedure

Each participant was randomly assigned to a team and a role (leader or member). There were no computer lab facilities at the school site so all data collection took place in classrooms that had ongoing instruction. Participants were arrayed in the back of the classroom to minimize the interaction with other students. The experimenters first introduced themselves and the study, then trained the students on the computer system and task, and then started the group concept mapping task. The training session took 13 minutes and the actual task 36 minutes. Leadership rotated every 6 minutes giving each participant the opportunity to control the concept map twice.

Results

Individual-Level Measures

Each of the 37 messages were used at some point. Table 3 lists the frequency counts for each message. As Table 3 shows, although all messages were used, individual message usage varied from 4 (message #15 – "What if we change [L] to [L]?") to 206 (message #34 – "No").

Table 3. Frequency Count of Messages

Msg. Number	Freq. Count	Msg. Number	Freq. Count	Msg. Number	Freq. Count
1	60	12	47	25	16
2	41	13	13	26	27
3	47	14	9	27	23
4(adapt)[1]	31	15	4	28	50
4(dec)[1]	23	16	34	29	47
4(lead)[1]	14	17	65	30	54
5	30	18	24	31	108
6	91	19	47	32	112
7	18	20	31	33	167
8	46	21	36	34	206
9	26	22	82	35	46
10	23	23	58		
11	13	24	30		

[1]Message 4 was presented to participants as a combination of three message types: adaptability, decision making, and leadership. The category of the message depended on the specific message selected.

Table 4 gives the frequency counts for each team process category. Interesting, decision making was used far less than the other processes. The frequency counts of the other categories show fairly uniform usage. These results contrast with the data from Pilot study 1, which showed varied overall usage by category (adaptability – 26%, coordination – 2%, decision making – 14%, interpersonal – 3%, leadership – 38%).

Table 4. Frequency Count of Process Category

Team process	Total (pct[1])	Mean	*SD*	Min.	Max.
Adaptability (Msg #: 4(adapt), 5, 7, 9, 29, 30, 31)	314 (17%)	6.98	4.59	1	18
Coordination (Msg #: 13, 17, 18, 19, 20, 21, 22)	298 (17%)	6.62	5.45	0	22
Decision making (Msg #: 4 (dec), 10, 11, 14, 15, 16)	106 (6%)	2.36	2.85	0	15
Interpersonal (Msg #: 23, 24, 25, 26, 27, 28, 32)	316 (18%)	7.02	5.09	0	23
Leadership (Msg #: 1, 2, 3, 4(lead), 6, 8, 12)	346 (19%)	7.69	5.27	0	18
Yes or No (Msg #: 33, 34)	373 (21%)	7.69	5.27	0	18
Error (Msg #: 35)	47 (3%)	1.04	1.51	0	7

[1]Percentages total to 101% due to rounding errors.

For each participant, individual scores were calculated for the adaptability, coordination, decision making, interpersonal, leadership and teamwork processes. The scores were computed by counting the number of messages belonging to each category. In addition, a communication score was computed by summing each of the five teamwork process scores for each individual, plus the number of "Yes" and "No" messages sent, less the total number of error messages for that individual. An individual's scale score was not adjusted for error messages. Table 5 gives means and standard deviations for each scale. As shown in Table 5, the average participant sent approximately 16% of the messages in each category.

Table 5. Individual-Level Teamwork Process Scales (*N*=45)

Process	Mean	*SD*	Min	Max
Adaptability	0.16	0.12	0.01	0.51
Coordination	0.16	0.14	0.00	0.59
Decision making[1]	0.13	0.18	0.00	0.81
Interpersonal	0.16	0.13	0.00	0.55
Leadership	0.16	0.12	0.00	0.42
Communication	0.78	0.35	0.15	1.85

[1]The decision making category contains 6 messages. Adaptability, coordination, interpersonal, and leadership contain 7 messages. Communication contains two messages, plus the composite of all other categories.

Team-Level Process Measures

Each of the individual-level teamwork process measures was used to calculate team-level scores. The individual scores for each process were summed among the three members of each team to generate a team score. Table 6 gives the means, standard deviations, and intercorrelations for each team-level teamwork process measure. Communication is a composite (simple sum) of the other five team process measures, plus the number of "Yes" and "No" messages sent, less the number of error messages sent.

Table 6. Descriptives and Nonparametric (Spearman) Intercorrelations for Team-Level Teamwork Process Measures (N=15).

Process	Mean	*SD*	2	3	4	5	6
1. Adaptability	.47	.25	-.38	-.50*	-.20	.24	-.18
2. Coordination	.47	.30		.40	.59**	-.24	.73**
3. Decision making	.40	.30			.18	-.32	.52*
4. Interpersonal	.47	.25				.15	.77**
5. Leadership	.47	.22					.03
6. Communication	2.33	0.60					

* $p < .05$. ** $p < .01$.

Team-Level Outcome Measures

The concept mapping task generated a total of five team-level outcome measures: semantic content score (stringent), semantic content score (categorized), organizational structure score, number of terms used, and number of links used. Table 7 gives the descriptive statistics for each measure.

Table 7. Descriptives Statistics for Team-Level Outcome Measures (*N* = 15)

Outcome measure	Mean	*SD*	Min	Max
Semantic content score (strict)	3.05	2.15	0.00	7.50
Semantic content score (categorized)	4.35	2.62	0.75	9.50
Organizational structure score	.19	.07	.10	.30
Number of terms used	13.87	3.96	7	18
Number of links used	17.00	5.95	8	26

As Table 7 shows, group maps were considerably lower than the expert criterion maps (stringent, *M*=19.25, *SD*=1.5; categorized, *M*=22.5, *SD*=21.5). This result is consistent with our pilot data and our assumption that our participants were content novices. This results also suggests that the Herl et al.'s (1996) scoring technique can discriminate between expert and novice concept maps.

Table 8. Nonparametric (Spearman) Correlations Between Team Processes and Outcome Measures ($N = 15$)

Team process	Semantic content score		Organizational structure score	No. of terms used	No. of links used
	Stringent	Categorized			
Adaptability	.06	-.11	-.29	-.41	-.46*
Coordination	-.54*	-.27	-.32	-.14	-.10
Decision making	-.43	-.26	-.24	-.08	.07
Interpersonal	-.40	-.24	-.30	-.21	-.10
Leadership	-.04	-.16	-.08	-.30	-.22
Communication	-.72**	-.52*	-.56*	-.40	-.23

* $p < .05$. ** $p < .01$.

As Table 8 shows, the correlation between communication and the semantic content scores and structure score was statistically significant. This result suggests that the more messages a group sent, the lower their concept mapping performance. This is consistent with our pilot data, which also showed a significant negative correlation between communication and semantic content score. What is curious is that the did not find a relationship between decision making and the semantic content scores in particular. Our pilot data show a positive relationship, as did our past work O'Neil et al. (in press-b).

Discussion

Our findings suggest that real-time measurement of teamwork skills is feasible. Clearly, students using our networked concept mapping system were able to jointly construct a concept map. The number of concepts used by groups ranged from 7 to 18 (maximum possible), and the number of links ranged from 8 to 26. Some groups had sparse maps while others had fairly complex maps. There was nothing in the data, observed by the experimenters, or reported during debriefing sessions that participants had difficulty grasping the notion of concept mapping or that they had difficulty (procedurally) making concept maps. Participants in our pilot studies did, however, consistently comment that they did not like the use of predefined messages. Participants reported that they felt the messages were too constrained and they wanted to type their own messages.

In terms of team performance, our results are consistent with our assumptions about participants. We assumed that participants had little content knowledge, and participants' semantic content scores were much lower than our experts. This suggests that Herl at al.'s (1996) concept map scoring algorithm can discriminate between experts and novices.

Our findings of no significant correlations between most team processes and outcome measures were unexpected. In particular, we expected the use of decision making messages to play a critical role in our group concept mapping task. Our decision making messages were designed to give participants the opportunity to consider alternatives among different links and concepts (e.g., "What if add 'producer' – 'requires' – 'carbon dioxide'?" or "We should think how 'producer', 'oxygen', and 'carbon dioxide' relate to each other."). We expected (as in O'Neil et al., in press-b) that the more teams used these kinds of messages the higher their team performance.

A possible explanation for these findings is that our task is highly knowledge dependent, and thus our participants lacked the requisite knowledge to be able to engage each other at a substantive level. The use of messages may reflect more the procedural aspects of constructing a concept map instead of any substantive discussion about the content. Support for this is seen in the total number of message usage by all groups. Decision making messages, which we designed to allow participant to discuss the content, accounted for 6% of messages use compared to 17%–21% for the other categories.

Another explanation is the split-attention effect (Sweller, 1994). While our task was fairly easy to carry out, the attentional demands were heavy. Selecting messages required participants to examine their message handout, drawing attention away from the map and messages that other members sent. Reading messages that other members sent draws attention away from focusing on the concept map, and constructing the map draws attention away from other members' messages. If focusing on the concept map is the most important contributor to constructing good concept maps, then it may have been the team leader who engaged others the least to have contributed the most. This is a reasonable assumption given the highly cognitive and knowledge driven nature of concept mapping.

Support for the split-attention effect is seen in correlations between overall concept map activity (i.e., the number of times a concept map node or link was added, moved, deleted, or revised). Statistically significant nonparametric (Spearman) correlations of large magnitudes were found between concept map activity and *every* outcome measure: semantic content score (stringent) – $r_S(15)=.69, p<.01$; semantic content score (categorized) – $r_S(15)=.71, p<.01$; organizational structure score – $r_S(15)=.68, p<.01$; number of terms used – $r_S(15)=.71, p<.01$; and number of links used – $r_S(15)=.58, p<.05$. These findings suggest that the most important facet of group concept mapping is paying attention to the concept map. The overall level of activity may have induced too heavy a cognitive load on participants.

These findings raise questions about our group concept mapping task relative to our teamwork process measures. In particular, what is a *team* and what is a teamwork task? A team is typically a group of individuals who (a) collectively share a common goal, and (b) are essential to the success of the team. The absence of an individual severely impacts the functioning of a team (McIntyre & Salas, 1995). The purpose of a team is to perform a task that cannot be performed by individuals alone. While this sometimes may be the goal in educational settings, more often the function of small groups in education is to improve individual learning (Webb & Palinscar, 1996). In our current work we have cast a teamwork perspective (as characterized by Tannenbaum et al., 1996) on a weak teamwork task. Our collaborative concept mapping task may be more like a small group task than a teamwork task. A measurement system based on teamwork processes may be insensitive to small group processes, which may partially explain our findings.

Despite these shortcomings we believe our approach to using networked computers to assess teamwork processes remains viable given the alternatives. The goal of large scale assessment of teamwork skills – let alone small scale ones – remains elusive. Existing approaches are labor and time intensive, often involving hundreds of hours of transcription and coding. These approaches have little practical value as an assessment option, being untimely and prohibitively expensive. Our software architecture is designed to be domain independent and should transfer to other computer-based team environments. Such a measurement system would offer the capability of quickly assessing team processes and outcomes in educational environments (K–12) or industrial or military training environments.

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