Implementation and Outcomes of Scaffolding Cyber-Enabled Collaborative Learning in Multiple STEM Courses

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Abstract

Students may struggle in achieving the optimal benefit in learning from their interaction with their peers in learning STEM courses because they may be not aware of effective social interaction strategies and cognitive strategies for the collaborative learning. In addition, coping with multiple different learning tasks and schedules, students may not be able to arrange time for the face-to-face discussion with all the team members. Therefore, online discussion may become a good platform for facilitating collaborative learning. This paper presents impacts of scaffolding collaborative learning through online discussion on learning processes and outcomes of students in multiple STEM courses. Students in the same team were assigned a shared learning task and required to co-construct their understanding of the course-related learning concepts and co-solve the assigned learning problems with their peers through online discussions that were carried out via group emails. The scaffolding from both social and cognitive perspectives was presented to students to provide a structure of effective collaborative knowledge construction processes. The scaffolding focuses on specifying, sequencing, and assigning roles or activities to students, and providing prompts for them to ask thought-provoking questions and follow the right cognitive procedures specific for problems at hands. While impacts of scaffolding online discussion revealed from the data collected from two engineering courses were reported in the last year ASEE conference paper, this paper presents results of data analysis of all the valid samples in five STEM courses, yielding findings that may be generalized for STEM courses. Those results indicate that the presented instructional framework with the proposed scaffolding can provide a platform for students to engage in more collaborative learning with their team peers than they did in traditional settings. The social interaction scaffolding may promote intellectual exchange among student team members, leading to enhancing students' satisfaction on online collaborative learning, social process for collaborative learning, intrinsic value on learning, and learning performance. The limitations of current findings and suggestions for future implementation are also discussed.

Introduction

Collaborative learning may enable students to deepen their learning and understanding of sophisticated subjects through social interactions, such as clarifying understandings, sharing ideas from various perspectives, and challenging opinions with peers[1, 2]. Through collaborative learning, students may learn far beyond the limit of what they can reach from their independent individual learning. The driving force behind collaborative learning is the social interactions in learning, which may provoke both cognitive and meta-cognitive processes in learning[3, 4, 5]. Therefore, collaborative learning is being acknowledged and utilized by more and more engineering faculty and students for facilitating learning. Koehn et al. had found that civil/construction-engineering students preferred collaborative learning[6]. A pilot survey conducted by the authors of this paper also revealed that STEM students at authors' institution also recognized the effectiveness of collaborative learning and the necessity of scaffolding for supporting collaborative learning.

In STEM field, Soundarajan proposed the Peer Instruction for online collaborative learning, in which students were assigned different roles in different tasks[7]. Bohorquez and Toft-Nielsen integrated collaborative learning in specific course instruction and revealed the effectiveness of problem-oriented method and collaborative learning in biomedical engineering education[8]. Dong and Guo developed and adopted the Collaborative Project-based Learning Model to promote students' collaborative learning in computer-networking curriculum, and claimed the improvement in students' concept knowledge and hands-on skills[9].They maintained that effective collaborative learning could not occur without proper scaffolding[9]. Those researchers or instructors tried to engage students in collaborative learning through course requirements and assignments, but they did not indicate whether they had provided detailed explicit scaffolding or guideline to systematically guide students' collaborative learning.

On the other hand, students with less social and cognitive skills may not carry out collaborative learning effectively without some instructional support, because they may not know how to successfully exchange ideas and share learning, particularly for those who have lower achieving, but may benefit more through interactions with their learning peers. To foster students' effective collaborative learning, cognitive science researchers have developed various types of scaffoldings to support effective group interaction in cognitive, meta-cognitive, and social processes to achieve optimal learning outcomes[10]. The most frequent method is to provide scripts that "specify, sequence, and assign roles or activities to collaborative learners" and set specific rules, to help learners effectively learn from their collaboration[5, 11, 12, 13, 14].

King claimed that students lacked of skills to spontaneously ask thought-provoking task-related questions[15]. Thus, King[16], Swan and Pead[17] had developed the guided peer questioning prompts to scaffold students to learning through questioning in collaborative learning. King also demonstrated the effectiveness of guided peer questioning prompts in fostering students' knowledge acquisition in empirical studies[18], and declared that "the guided peer questioning could prompt the high level interaction, including activities such as asking thought-provoking questions and integrating new knowledge"[19]. Hron et al confirmed the positive influence of provided scripts on smoothing the collaborative learning process[20]. Weiland provided different levels of computer-supported collaboration scripts to high school students in a simulation-based learning environment, and revealed that students with precise instruction guidance could offer more suggestions supported by personal experiences and learning materials, and that those students also outperformed those with general instructional orientation[5]. Weiland's findings suggest that the different level of scaffolding could affect both learning process and learning outcomes.

The findings from cognitive science research could provide theoretical and methodological basis for STEM instructors to establish an effective scaffolding model to assist their students' collaborative learning in STEM fields. Nevertheless, few research efforts have been made to examine effects of instructional scaffolding for cyber-enabled collaborative learning based on those findings on students' learning in the authentic STEM education setting, particularly for African-American students. While a framework of scaffolding online discussion and its impacts revealed from the data collected from two engineering courses were adopted and reported in the last year ASEE conference paper [21], this paper presents its impacts based on results of data analysis of all the valid samples in five STEM courses, yielding findings that may be generalized for STEM courses.

Instructional framework for scaffolding collaborative learning in stem courses

Authors had adopted and developed an instructional framework for scaffolding collaborative learning in STEM courses based on cognitive science research findings. This adopted framework includes two perspectives. One is the social interaction scaffolding that specifies roles, sequences group activities, and provides question prompts for social interactions among student team members to effectively engage them in task-related social interaction. The other is the cognitive cooperation scaffolding that guides students' cognitive processes relating to the specific learning tasks at hands. Detailed description of the two types of scaffolding can be retrieved from the previously published ASEE conference paper [21].

Table 2 Different students' team groups and corresponding instruction (input variables)

Team Groups	Instructional Materials Provided to Students
A	Collaborative learning requirements only
B	Collaborative learning requirements and Social Interaction Prompts
C	Collaborative learning requirements and Cognitive Process Prompts
D	Collaborative learning requirements, Social Interaction Prompts, and Cognitive Process Prompts

Table 3 Outcome variables

Outcome Variables	Dimensions and Sub-Dimensions		Instruments
Learning Process	Social processes: Social modes of co-construction [22]	Externalization	Students' self-report survey on collaborative learning process
		Elicitation	
		Quick consensus building	
		Integration-oriented consensus building	
		Conflict-oriented consensus building	
	Cognitive processes: Epistemic (cognitive) activities [22]	Construction of problem space	
		Construction of conceptual space	
		Construction of relations between conceptual and problem space	
Learning outcomes	GPA		Grades
	Knowledge (Deep understanding of important concepts)		Concept inventory
	Disposition (Motivation and learning skill), Experience, and Satisfaction		MSLQ, self- report survey

Table 4 Data collection procedures and schedules

Phases	Contents	Duration
(1) Pre-tests	Demographics , computer experience, GPA	Two weeks
	Knowledge on selected subjects through Concept Inventory	
	Learning disposition measured through MSLQ	
(2) Collaborative learning through online discussion	Online discussion for collaborative learning	Ten weeks
	Students' Self-report on collaborative learning process	
	Instructors' observation of students' collaborative learning	
(3) Post-tests and debriefing	Learning experience and Satisfaction, comments	Two weeks
	Knowledge on selected subjects through Concept Inventory	
	Learning disposition measured through MSLQ	

Implementation process and data collection

The presented instructional framework had been implemented in five STEM courses in the fall semester of 2013, including one chemistry course: General Chemistry; one computer course: Operating Systems; one mathematics course: Calculus; and two engineering courses: Statics and Structural Analysis, with total 334 students. In each class, students were randomly assigned into 4-member teams, and then student teams were randomly assigned into four different groups. All the students were required to work collaboratively within their own teams through an online discussion by using group e-mail. Students in the same course were provided with the same three assignments for their collaborative learning in the semester, including two basic problems related to important concepts and one sophisticated problem-solving task. The collaborative learning process lasted for about two months. However, different groups of teams were provided with different levels of scaffolding as indicated in Table 2. Detailed description of the implementation process can be retrieved from a previously published ASEE paper by the authors [21].

The impacts of implementation of the presented scaffoldings were measured in terms of students' learning processes and learning outcomes, as well as their learning experience and satisfaction with the scaffoldings, and change of their learning dispositions. The variables of students' collaborative learning processes were categorized into social processes and cognitive processes with total eight dimensions as shown in Table 3 based on Fischer's Knowledge Co-Construction Model[22]. The variables of students' learning outcomes include their GPA, deep understanding of important course concepts, and learning dispositions, as well as their learning experience, and satisfaction with the presented scaffoldings. Those variables of impacts are summarized in Table 3. The data collection procedures and schedules are outlined in Table 4.

Variables of the students' collaborative learning processes were obtained from students' self-report questionnaires designed based on Fischer's Model[22], in which students were asked to provide the Likert scale of 1 to 5 to indicate the frequency with which they involved in the specific processes of each dimension of collaborative learning processes as specified by Fischer's Model[22]. The students' deep understanding of important course concepts was measured in terms of the test scores of Concept Inventory, which is a test of multiple choices on specific course related concepts. The change of students' learning dispositions was measured in terms of their learning motivation and learning skills by using the self-report Motivated Strategies for Learning Questionnaire (MSLQ) developed by Printrich et al[23]. Students' learning experience and satisfaction with the presented scaffoldings was measured by using self-report surveys. Students' participation in those self-report surveys was voluntary. The implementation and data collection plan was reviewed and approved by the IRB at authors' institution.

Data analysis and its results

In pre-test, 140 sets of valid surveys were collected from all five courses, in which 37 sets were in Group A, 35 in Group B, 35 in Group C and 33 in Group D. One-way ANOVA analysis on students' perceptions in pretest demonstrated no significant difference among control group (Group A) and intervention groups (Group B, C, and D). This indicated that all the participants could be considered to be on the same benchmark. The description also showed that participants were confident of their computer literacy, and that they had learned collaboratively through questioning. Most participants, however, were not sure about the effectiveness of collaborative learning.

Table 5 Students' Online Collaborative Learning Experience from Mid-Term Survey

Survey Questionnaires	Student Group	Mean	Std. Deviation
It is easy to communicate with my team members through the online discussion.	Group A	2.78	1.35
	Group B	2.58	1.40
	Group C	2.72	1.37
	Group D	3.18	1.29
I know how to discuss properly with team members to help me learn the concept and find the solution through the online discussion process.	Group A	2.70	1.20
	Group B	3.14	1.27
	Group C	3.34	1.29
	Group D	3.38	1.16
The members in my group collaborate with each other effectively.	Group A	3.15	1.17
	Group B	3.33	1.39
	Group C	2.91	1.42
	Group D	3.29	1.45
The online discussion process is effective in helping me to learn the course content.	Group A	2.40	1.15
	Group B	2.67	1.35
	Group C	2.44	1.32
	Group D	2.91	1.29
It motivates me to learn through the use of online discussion.	Group A	2.60	1.24
	Group B	2.78	1.27
	Group C	2.19	1.28
	Group D	2.91	1.44
I follow the guideline for online discussion provided by instructors through online system.	Group A	3.40	1.19
	Group B	3.44	1.18
	Group C	3.63	1.04
	Group D	3.53	1.13
The guideline for online discussion provided by instructors through online system helps our team remain engaged in collaborative learning.	Group A	2.88	1.11
	Group B	3.03	1.13
	Group C	2.63	1.26
	Group D	3.24	1.33
The team members post question or content relevant to the course content.	Group A	2.90	1.45
	Group B	3.03	1.21
	Group C	3.47	1.19
	Group D	3.24	1.33
Team online discussion makes me reflect on the course content in a deeper level.	Group A	2.88	1.24
	Group B	2.72	1.06
	Group C	2.75	1.32
	Group D	2.91	1.42
I frequently respond to the post from my group members through online discussion.	Group A	3.53	1.45
	Group B	3.28	1.11
	Group C	3.53	1.41
	Group D	3.53	1.24

Note: Group A, n = 40; Group B, n = 36; Group C, n = 32; and Group D, n = 34. Totally, N = 142.

Students' online collaborative experience was examined in the mid-term survey, as shown in Table 5. The results demonstrate that the students in intervention groups (Group B, C, and D) generally experienced more collaborative learning than those in the control group (Group A). Specifically, students in Group D with both social and cognitive cooperation scaffolding gave more active responses when asked questions on the process of communicating with team members and the effectiveness of collaborative learning. Group B with social cooperation scaffolding reported the highest scores corresponding to the survey item "The members in my group collaborate with each other effectively." Group C with cognitive cooperation scaffolding expressed the highest level corresponding to questions related cognitive processes. However, they showed the lowest levels when they rated the survey items "The members in my group collaborate with each other effectively", "It motivates me to learn through the use of online discussion", and "The guideline for online discussion provided by instructors through online system helps our team remain engaged in collaborative learning." This result agrees with Weinberger's findings[10] that students under the cognitive scaffolding tended to study solitarily because the guideline provided in the cognitive scaffolding make it easy for students to learn by themselves, which might compromise the need of collaborative learning.

Results from the satisfaction survey, as shown in Table 6 and 7, revealed that students in the intervention groups were generally more satisfied with online collaborative learning than those in control group. Students in Group B expressed significantly more satisfaction with online collaborative learning as an important and effective learning ($MD=1.09$, $p<0.05$) and problem-solving ($MD=0.83$, $p<0.05$) tool than Group A. Comparison between Group B, C, and D shows that students who received the Social Interaction scaffolding in the group B were much more satisfied with online collaborative learning and its scaffoldings. This could be explained by the findings of Weinberger [10] and Mayer, Heiser and Lonn [24], i.e., cognitive overload in hypermedia environments could compromise students' learning. Too much scaffolding increased students' cognitive load by requiring students to think too much about both social and cognitive strategies for online discussion, which would decrease students' satisfaction over the online collaborative learning. Another reason might be that students received both social and cognitive scaffoldings might expect more from the online collaborative learning. Too much expectation would also lead to their lower satisfaction over the whole process. However, the fact that students in Group D expressed higher satisfaction than those in Group C indicates again that the social cooperation scaffolding might be effective in fostering students' online collaborative learning.

Table 6 Students' Satisfaction on Online Collaborative Learning

Question	Group	Mean	Std. Deviation
The team-based discussion through online system is very import tool and I am interested at using them for my learning and problem solving.	Group A	2.20	1.05
	Group B	3.29	1.18
	Group C	2.58	1.35
	Group D	2.94	1.27
The team-based discussion through online system is practical and useful in helping learn and master important concepts in the course.	Group A	2.37	1.11
	Group B	3.20	1.11
	Group C	2.61	1.17
	Group D	3.03	1.29
The instruction materials for the team-based discussion through online system are organized effectively.	Group A	2.86	1.22
	Group B	3.60	1.04
	Group C	3.15	1.12
	Group D	2.03	1.16
The instruction materials for the team-based discussion through online system are presented clearly.	Group A	3.23	1.29
	Group B	3.74	1.04
	Group C	3.48	1.06
	Group D	3.15	1.18
The instruction materials for the team-based discussion through online system help me participate in online discussion and effectively exchange ideas with other team members.	Group A	2.54	1.22
	Group B	3.23	1.24
	Group C	2.88	1.32
	Group D	3.15	1.18

Note: Group A, n = 35; Group B, n = 35; Group C, n = 33; and Group D, n = 33. Totally, N = 136.

Students' online collaborative learning processes were measured by a survey with eight dimensions as demonstrated in Table 9, which fall into two major variables: social processes and cognitive processes as shown in Table 8. The results in Table 9 indicate that students in Group B and C reported more engagement in social and cognitive processes in the collaborative learning. However, students in Group D, who received both social and cognitive scaffoldings, did not show any advantage in either social or cognitive learning progress. This might also result from cognitive overload as discussed in the previous section. When eight dimensions of learning processes were considered (see Table 9), students in Group B and C demonstrated advantage in most items. Students in Group B enjoyed the highest mean score. However, Group D suffered lower scores in most dimensions. The most significant differences exist between groups in the dimension of Elicitation. Comparison results indicate that Group B might asks significantly more questions relating to problems than Group A, while Group D might ask significantly less questions than Group B. These results suggest that the social cooperation scaffolding might be effective in fostering students' collaborative learning through asking questions, but cognitive cooperation scaffolding might hinder students' cooperation in learning.

The impacts of scaffolding on students' learning dispositions measured by MSLQ [23] were examined by comparing results between the post-test and the pre-test in terms of size effect, as shown in Table 10. According to the comparison, Group B enjoyed the increase in self-efficacy, intrinsic value, cognitive strategy use and self-regulation, but suffered intensified test anxiety. Group C, similar to Group D, experienced increase in self-efficacy and reduced test anxiety, but failed to develop in intrinsic value cognitive strategy use and self-regulation. However, Group D enjoyed the boldest increase in self-efficacy and largest decrease in test anxiety, but they suffered the largest decrease in intrinsic value, cognitive strategy use.

Table 7 Group Comparison of Students' Satisfaction on Online Collaborative Learning

Question	Comparison Groups		Mean Difference	Effect Size
The team-based discussion through online system is very import tool and I am interested at using them for my learning and problem solving.	Group B	Group A	1.09*	1.04
	Group C	Group A	0.38	0.36
	Group D	Group A	0.74	0.70
	Group C	Group B	-0.71	-0.60
	Group D	Group B	-0.35	-0.30
	Group D	Group C	0.36	0.27
The team-based discussion through online system is practical and useful in helping learn and master important concepts in the course.	Group B	Group A	0.83*	0.75
	Group C	Group A	0.24	0.22
	Group D	Group A	0.66	0.59
	Group C	Group B	-0.59	-0.53
	Group D	Group B	-0.17	-0.15
	Group D	Group C	0.42	0.36
The instruction materials for the team-based discussion through online system are organized effectively.	Group B	Group A	0.74*	0.61
	Group C	Group A	0.29	0.24
	Group D	Group A	0.17	-0.68
	Group C	Group B	-0.45	-0.43
	Group D	Group B	-0.57	-1.51
	Group D	Group C	-0.12	-1.00
The instruction materials for the team-based discussion through online system are presented clearly.	Group B	Group A	0.51	0.40
	Group C	Group A	0.26	0.19
	Group D	Group A	-0.08	-0.06
	Group C	Group B	-0.26	-0.25
	Group D	Group B	-0.59	-0.57
	Group D	Group C	-0.33	-0.31
The instruction materials for the team-based discussion through online system help me participate in online discussion and effectively exchange ideas with other team members.	Group B	Group A	0.69	0.57
	Group C	Group A	0.34	0.28
	Group D	Group A	0.61	0.50
	Group C	Group B	-0.35	-0.28
	Group D	Group B	-0.08	-0.06
	Group D	Group C	0.27	0.23

Note: Group A, n = 35; Group B, n = 35; Group C, n = 33; and Group D, n = 33. Totally, N = 136. The mean difference with * is significant at the 0.05 level. Effect Size = difference between means of comparison groups divided by the Std. deviation of the latter groups.

Table 8 Students' Learning Process

	Intervention Group	Mean	Std. Deviation
Social Process	Group A	2.93	0.68
	Group B	3.37	0.66
	Group C	3.18	0.79
	Group D	2.76	0.99
Cognitive Process	Group A	2.96	0.79
	Group B	3.31	0.81
	Group C	3.15	0.91
	Group D	2.90	1.12

Note: Group A, n = 35; Group B, n = 34; Group C, n = 33; and Group D, n = 34. Totally, N = 136.

Table 9 Eight Dimensions of Students' Learning Process

Dimensions	Comparison Groups		Mean Difference	Effect Size
Externalization	Group B	Group A	0.41	0.41
	Group C	Group A	0.21	0.21
	Group D	Group A	-0.27	-0.27
	Group C	Group B	-0.20	-0.19
	Group D	Group B	-0.68	-0.65
	Group D	Group C	-0.48	-0.42
Elicitation	Group B	Group A	0.68*	0.63
	Group C	Group A	0.27	0.25
	Group D	Group A	-0.06	-0.06
	Group C	Group B	-0.41	-0.38
	Group D	Group B	-0.74*	-0.69
	Group D	Group C	-0.33	-0.35
Quick consensus building	Group B	Group A	-0.02	-0.02
	Group C	Group A	0.21	0.22
	Group D	Group A	-0.46	-0.48
	Group C	Group B	0.23	0.22
	Group D	Group B	-0.44	-0.42
	Group D	Group C	-0.67	-0.65
Integration-oriented consensus building	Group B	Group A	0.66	0.64
	Group C	Group A	0.46	0.45
	Group D	Group A	0.05	0.05
	Group C	Group B	-0.20	-0.20
	Group D	Group B	-0.61	-0.62
	Group D	Group C	-0.41	-0.34
Conflict-oriented consensus building	Group B	Group A	0.49	0.50
	Group C	Group A	0.10	0.10
	Group D	Group A	-0.10	-0.10
	Group C	Group B	-0.39	-0.41
	Group D	Group B	-0.59	-0.62
	Group D	Group C	-0.20	-0.19
Construction of problem space	Group B	Group A	0.44	0.46
	Group C	Group A	0.30	0.32
	Group D	Group A	-0.03	-0.03
	Group C	Group B	-0.14	-0.16
	Group D	Group B	-0.47	-0.55
	Group D	Group C	-0.33	-0.32
Construction of conceptual space	Group B	Group A	0.38	0.43
	Group C	Group A	-0.03	-0.03
	Group D	Group A	-0.06	-0.07
	Group C	Group B	-0.41	-0.39
	Group D	Group B	-0.44	-0.42
	Group D	Group C	-0.03	-0.03
Construction of relations between conceptual and problem space	Group B	Group A	0.24	0.25
	Group C	Group A	0.30	0.31
	Group D	Group A	-0.09	-0.09
	Group C	Group B	0.06	0.07
	Group D	Group B	-0.33	-0.36
	Group D	Group C	-0.39	-0.38

Note: Group A, n = 35; Group B, n = 34; Group C, n = 33; and Group D, n = 34. Totally, N = 136. The mean difference with * is significant at the 0.05 level. Effect Size = difference between means of comparison groups divided by the Std. deviation of the latter groups.

Table 10 Students' Motivational and Self-Regulated Learning Components

Measurement	Group	Pre-Test		Post-Test		Growth
		Mean	Std. Deviation	Mean	Std. Deviation	Effect Size
Self- Efficacy	Group A	5.81	0.63	5.71	0.95	-0.16
	Group B	5.58	1.32	5.63	1.30	0.04
	Group C	5.35	0.91	5.44	1.29	0.10
	Group D	5.43	0.78	5.53	1.01	0.13
Intrinsic Value	Group A	5.88	0.63	5.79	0.77	-0.14
	Group B	5.87	0.97	6.05	0.62	0.19
	Group C	5.77	0.92	5.62	1.06	-0.16
	Group D	6.02	0.59	5.83	1.02	-0.32
Test Anxiety	Group A	3.76	1.40	3.92	1.48	0.11
	Group B	4.65	1.30	5.04	1.35	0.30
	Group C	4.25	1.80	3.94	1.94	-0.17
	Group D	4.73	1.84	4.11	1.66	-0.34
Cognitive Strategy Use	Group A	5.30	0.80	5.39	0.79	0.11
	Group B	5.30	0.86	5.57	0.77	0.31
	Group C	5.53	0.81	5.46	0.90	-0.09
	Group D	5.60	0.71	5.53	0.85	-0.10
Self- Regulation	Group A	5.21	0.99	5.27	0.90	0.06
	Group B	4.97	0.90	5.04	0.93	0.08
	Group C	5.21	0.85	5.07	1.03	-0.16
	Group D	5.17	1.05	5.03	1.11	-0.13

Note: Group A, n = 26; Group B, n = 23; Group C, n = 26; and Group D, n = 20. Totally, N = 95. Effect Size = difference between means of post-test and pre-test divided by the Std. deviation of pre-test

Table 11 Students' Concept Acquisition

Group	Pre-Test		Post-Test		Growth
	Mean	Std. Deviation	Mean	Std. Deviation	Effect Size*
Group A	39.81	16.46	53.65	23.52	0.84
Group B	41.67	18.80	62.50	24.93	1.11
Group C	36.90	15.45	57.38	29.10	1.33
Group D	35.88	15.23	52.65	28.51	1.10

Note: Group A, n = 26; Group B, n = 24; Group C, n = 21; and Group D, n = 17. Totally, N = 88. Effect Size = difference between means of post-test and pre-test divided by the Std. deviation of pre-test.

The impacts of scaffolding on students' understanding of learning subjects, measured by the Concept Inventory, which is a multiple choice problem test on specific course contents, are revealed by comparing results between the Concept Inventory tests in pre- and post-test. The comparisons among the four student groups are demonstrated in Table 11. The results indicate that students with scaffoldings (Group B, C, and D) gained more progress than the control group (Group A). This demonstrated the effectiveness of scaffolding in promoting students' concept learning. Students in Group C gained the boldest progress, which may be attributed to that cognitive scaffolding could help students deal with concept learning directly, and that its influence was more direct. The students who received both social and cognitive scaffolding had less gain in learning subjects when compared to those in Group B and C. This may result from cognitive overload in online collaborative learning.

Discussion

According to findings from data analysis, students in all groups were at the same benchmark. After receiving different scaffoldings, intervention groups demonstrated more active responses in collaborative-learning-related questions in the midterm survey. However, students in Group C showed lower level of cooperation in collaborative learning. At the end of the implementation, the satisfaction survey revealed that students in Group B were significantly more satisfied with online collaborative learning as an important and effective learning. Students in Group D, however, reported less satisfaction than those in Group B and C. The investigation on students' learning processes also demonstrated the effectiveness of social cooperation scaffoldings and the possible negative side effect caused by cognitive cooperation. The results from the concept inventory test demonstrated the effectiveness of both social and cognitive scaffoldings in promoting students' concept learning, and proved the effectiveness of cognitive scaffolding in academic learning.

The survey on students' learning dispositions showed that the social interaction scaffolding could increase students' self-efficacy, intrinsic value, cognitive strategy use and self-regulation in learning, but it could also increase students' Test Anxiety. This may result from the intensified peer pressure. The social interaction scaffolding promotes more social interaction among peers for learning subjects, which might cause peer pressure because it lets students feel the importance of learning and test score. On the other hand, the cognitive process scaffolding may enhance students' self-efficacy and reduce their test anxiety. This consists with the findings by Weinberger[10], i.e., under cognitive process scaffolding, students feel that they are able to easily solve the problem at hands, leading to students' overconfidence. However, when both social and cognitive scaffolding were provided together to students, they might cause cognitive overload and lead to negative impacts on the students' learning disposition. The results also indicate that offering both social and cognitive cooperation scaffolding to students may negatively affect their self-regulated learning skill development, because they relied more on the external scaffolding rather than the internal regulation on their own.

Besides the analysis results from the surveys, students also provided their comments and suggestions on the online collaborative learning and its scaffoldings. Most of the students reported benefits from the team-based discussion with the online system in mastering concepts in their courses. The majority of students attributed the improvement to the social process of the team-based online discussion. However, results also revealed that most of students' discussion were only at the category of externalization and elicitation, such as, "(we can) exchange information", "… it gives me the chance to see how others think aside from myself", "(I am) able to check work against others", "… it gives me the opportunity to seek help on things I don't know", and "… it was easy for (me) to ask a team member a question." Most of those students who reported benefits from online collaborative learning could clearly indicate some important learning concepts they had mastered from the online discussion, in which "team work" is the most frequently mentioned concept they mastered. This information proved what we found in the quantitative data analysis above.

A few students stated some negative comments and complained of uncooperative team members or the lack of skills in online collaborative learning. They listed some factors that prohibited them from effective collaborative learning, which included "it is hard for other team members to collaborate", "…all team members were not involve", "…lack of communication, team members left out or neglected", "…its forgetful to go online for a discussion with the team members", "it's easier to communicate and learn in person", "(I need) clearer concept of requirements for discussion", and "…too much is expected and not knowing enough information." Many students suggested that the scaffoldings could offer more detailed instructions and mentioned that the online collaborative learning was not a usual method for them. Almost all of them reported that much more time were spent on learning on their own than that on online collaborative learning. From these comments, it can be found that students need the social interaction scaffolding in their online collaborative learning, and that they need to be facilitated to learn collaboratively online.

The course instructors also found in their observation the fact that students engaged in more interactions with their peers for their learning subject with the online collaborative assignment than they did in the class without collaborative learning assignment. Most of teams could initiate questions regarding the learning contents through online system. They also came together to the instructor office to ask questions that they could not solve by themselves. This is the indication that providing collaborative learning assignment may prompt students' interaction with their peers. However, not all discussion questions were answered by team members through the online system. Some students preferred engaging in the face-to-face discussion than online discussion. Some students preferred communicating with others via their cell phone using text messages, rather than the group e-mail, and some students even had never used e-mail system. Instructors also found that some students still were not socially connected, even though they were assigned into the same discussion team.

The complaint on uncooperative team members may be attributed to the reason that the online discussion is not a synchronic one and students could hardly find time to discuss online at the same time after class. Therefore, most students could not get prompt response or feedback from their team members. This delay might make some students who were waiting for the responses online feel that their peers were not cooperative, and became frustrated, even though their peers might respond as soon as they saw the message online. This asynchronous online discussion might affect students' participation interest and prevent them from achieving better results from online collaborative learning. This calls for improvement in this area in future implementation.

Some instructors also judged that some students might not really perceive the value of collaborative learning, and still prefer learning solitarily. Even through students were indulged in internet and online chatting, they might lack of skills in learning collaboratively through online discussion and failed to communicate continuously online to achieve a specific learning objective. They preferred synchronic communication, such as instant message communication. Lack of simultaneous feedback also affected students' interest in participating in collaborative learning through online discussion. Students might also need more scaffolding in applying the skills to achieve more profound learning.

Limitation of this paper and future research and improvement

Even though the proposed scaffolding was implemented in five STEM courses with totally 339 students, not all students participate in evaluation data collection process. Some students did not complete all the survey questionnaires. In addition, some instructors did not collect all the data as planned. All these resulted in small and different sample size among collected data in each measurement and led to the consequence that the sample sizes in each of four different groups may not be large enough to reveal the statistical significance. For example, there were only 95 students who took both pre-test and post-test of MSLQ, leading to that there were only about 20 students in each intervention groups. Besides, the presented learning process data were mainly obtained from students' self-report surveys and may contain subjective biases of participating students.

Thus, findings based on results from analysis of available data only reveal the possible trend of impacts of the proposed scaffolding as preliminary conclusions and need further confirmation with more data. Therefore, future research should include data collected from more participating students to reveal impacts of the scaffolding among different student groups with the statistical significance. The students' learning processes should be further characterized and evaluated in the future research based on more objective-based data, such as students' online discussion threads. The first-year implementation also suggests that a dedicated platform for collaborative learning through online discussion should be provided with the capacity for closely monitoring students' participation. Besides, students should be assigned with more carefully designed assignments or project, which requires close interactions among individual team members in order to complete the project or assignment, so that students could engage in more collaborative learning.

Conclusion

Based on the data analysis and discussion, conclusions can be reached that the presented instructional framework based on the proposed scaffolding may provide a platform for students to engage in collaborative learning with their team peers for co-constructing their knowledge. The social interaction scaffolding may enhance intellectual exchange among student team members, foster their social process for collaborative learning, and increase their intrinsic value on learning and learning performance. On the other hand, the social interaction scaffolding may also increase students' test anxiety. The cognitive process scaffolding may improve students' collaborative learning process, and self-efficacy, and also enhance students' learning performance. When both social interaction scaffolding and cognitive process scaffolding were provided to students, the scaffoldings may cause cognitive overload for students, and may not yield the desirable collaborative learning outcomes. The further evaluation should be carried out to further confirm the above preliminary conclusions based on more objective data collected from more samples without subjective biases. The other new measurements for improving students' learning engagement should be considered and included in the online collaborative learning research.

Acknowledgements

The authors gratefully acknowledge the support of the National Science Foundation under the grant NSF/HRD # 1332591. The authors thank the participating course instructors for their contribution of implementing presented instructional framework. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Authors also thank Dr. Troy Milliken for his contribution to the project implementation, and Dr. Yu-chun Kuo for her contribution as the project evaluator. Authors also thank graduate students Ms. Haiyan Zhou, Mr. Yanhua Cao, and Mr. Yujing Nie for their assistance in collecting and analyzing students' learning data and input them in an organized format.

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