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Exploratory study on the patterns of online interaction and knowledge co-construction in project-based learning

Heeok Heo [a], Kyu Yon Lim [b,*], Youngsoo Kim [c]

[a] Department of Computer Education, Sunchon National University, 315 Maegok-dong, Sunchon, Chonnam 540-742, South Korea
[b] Pre-service Teacher Education Program, University College, Ajou University, San 5 Wonchen-dong, Yeongtong-ku, Suwon, South Korea
[c] Department of Educational Technology, Ewha Womans University, 11-1 Seodaemoon-ku, Daehyun-dong, Seoul, South Korea

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ABSTRACT

This study aims to investigate the patterns and the quality of online interaction during project-based learning (PjBL) on both micro and macro levels. To achieve this purpose, PjBL was implemented with online group activities in an undergraduate course. Social network analysis (SNA) and content analysis were employed to analyze online interaction during project work. According to the SNA results generated from the online discussion boards, the group cohesiveness of seven teams, indicated by density indices, varied considerably, from as low as 9.81 to as high as 30.00. Regarding the content analysis of two teams with high project scores (Teams F and G), team members not only shared information (Phase I), but also identified the areas of disagreement and clarified the goals and strategies (Phase II). They also conducted some negotiations (Phase III). However, team members with low project scores (Teams C and E) shared information and stated their opinions in most cases (Phase I), with not much social construction in the higher level. Although both Team C and G showed high level of group cohesiveness among the seven teams, it is notable that the high-performing Team G dedicated nearly 39.3 percent of online discussion to negotiating and co-constructing knowledge, contrary to the 5.9 percent of low-performing Team C. Based upon the findings, some implications were proposed for further research.

1. Introduction

Project-based learning (PjBL) is an essential model embodying the social–cultural perspectives of learning in educational settings. Given that a project is pertinent to learners' real worlds, requiring collaborative investigation and the production of a series of project artifacts, learners are able to acquire process skills such as planning, implementing, and monitoring of a project as well as the content knowledge (Laffey, Tupper, Musser, & Wedman, 1998). Blumenfeld et al. (1991) described two components of PjBL: problems to be solved (or tasks to be accomplished), and tangible products as a result of the project. They also argued that the students, in PjBL, should actively participate in the entire process of asking and refining questions, debating ideas, designing plans and experiments, gathering information, drawing conclusions, and communicating their ideas, especially when the project is conducted by teams not by individuals.

The social engagement during project work is vital for genuine educational experiences (Dewey, 1916/1980; Hmelo-Silver, Chernobilsky, & Jordan, 2008; Katz & Chard, 2000; Lipson, Epstein, Bras, & Hodges, 2007). Despite its potential, some challenges arise when applying project work in traditional classroom settings, for example, additional time demands beside class hours placed on students to interact with peers and to engage in project work (Thomas & MacGregor, 2005). Students' interactions are often limited in face-to-face contexts, even though active interaction among group members is a key factor for successful project work (Blumenfeld et al., 1991; Krajcik, Czerniak, & Berger, 1999). When learners have more opportunities to interact with each other with fewer temporal and spatial limitations, they might obtain more productive outcomes from project work. That is why many scholars pay attention to the use of information and communication technology (ICT) when implementing PjBL.

* Corresponding author. Tel.: +1 82 31 219 3775; fax: +1 82 31 219 1620.
E-mail address: klim@ajou.ac.kr (K.Y. Lim).

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Computer-mediated communication (CMC) is an effective tool in PjBL as it extends learners' interaction beyond time and space limitations. Such tools as electronic boards, emails and online chatting provide learners with more chances to express their feelings, to share their ideas and to co-create learning outcomes. However, learners face some difficulties in using the electronic tools in PjBL (Edelson, Gordon, & Pea, 1999; Hou, Chang, & Sung, 2007; Krajcik et al., 1998). Learners might misunderstand peers' opinions when they just read the descriptions written by their peers (Paloff & Pratt, 2001). They also struggle with managing their time effectively (Williams van Rooij, 2009). Besides, learners sometimes work alone without sufficient interaction with others when it is hard to meet online due to schedule conflicts. Therefore, more attention should be paid to the way online interaction can be employed to achieve successful project work. There are some studies examining online interactions in the context of PjBL, but they have made limited analyses of the interaction: either content analysis at the micro level or participation frequency at the macro level (Hou et al., 2007; Thomas & MacGregor, 2005). When both views of the micro and macro levels are taken in analyzing the relationships of online interactions and project work, it allows deeper and broader understanding of the role of online interaction in PjBL.

This study aims to investigate the patterns and the quality of online interaction during PjBL on both micro and macro levels. To achieve this purpose, PjBL was implemented with online group activities in an undergraduate course. Social network analysis (SNA) and content analysis were employed to analyze online interaction during project work. Research questions are as follows:

(1) What are the interaction patterns of each team in project-based learning?
(2) How different are the social constructions of knowledge between the teams with high and low project performances?

2. Theoretical background

2.1. Social learning in PjBL

A recent trend in learning paradigm emphasizes socio-cultural aspects of learning which insist learning is inherently social and situated (Palincsar, 1998), incorporating dynamic processes of individual and social construction of knowledge building (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). Even though knowledge construction is basically a cognitive process, knowledge is developed through interaction between the knower and the known rather than cumulated in individual minds only (Stahl, 2000; van Aalst, 2009). PjBL is an exemplary model of the social learning perspective (Hmelo-Silver et al., 2008). In PjBL students with different levels of knowledge and prior experience work together in small groups toward a common goal which is pertinent to their real contexts. Since Kilpatrick (1918) made claims in his manuscript entitled "The Project Method", project-based learning has been applied to a variety of fields in education. Originally his idea had come from the educational thoughts of John Dewey who described learning as the continuing reconstruction of experience, and knowledge construction through a shared experience and a conjoint action with others (Dewey, 1916/1980). Although PjBL might be implemented either in individual or in collaborative contexts, considering the notion of Dewey's social aspects of learning, there is no doubt that learners are likely to achieve better outcomes from PjBL in collaborative contexts. They are not only able to co-produce project artifacts but also able to co-construct knowledge through social interaction and peer assistance in collaborative PjBL.

Authentic task, one of the essential features of PjBL, requires students to work collaboratively. In most cases, authentic tasks reflect real-world problems which require team experience and are situated in their real life (Dewey, 1933/1989; Helle, Tynjala, & Olkinuora, 2006; Lave & Wenger, 1991). Working with projects in school learning provides an opportunity for learners to encounter real problems and to combine their knowledge in order to solve the authentic problems. Even though there are some challenges like curriculum adjustment, project design, time management, and peer collaboration for integrating project methods into formal educational systems (Gülbahar & Tinmaz, 2006), solving realistic problems and producing concrete artifacts through group work are critical for learners to generate genuine experience, especially in higher education. While school work focuses on individual achievement and internalization of knowledge, much activity outside school in the real world requires collaboration and practical participation for socially shared accomplishment (Resnick, 1987). Social engagement, addressing the social perspective of PjBL, connects individuals' achievements from school learning and collaborative group work in real situations. In the socio-cultural view of learning, knowledge is socially constructed through active interaction and externally mediating actions (Gunawardena, Lowe, & Anderson, 1997; Pea, 1993; Vygotsky, 1934/1986). The thinking and feeling of each individual may be influenced by controversial discussion with others in a group and the individuals perhaps reconstruct their perspectives, affected by the opinions of other members of the group. In this way, knowledge is extended individually as well as socially, and the social construction of knowledge plays an important role in obtaining successful outcomes in PjBL.

The socio-cultural learning of PjBL may effectively occur in using interaction tools in online learning environments. CMC tools such as bulletin boards and blogs provide learners with more opportunities to share their knowledge and skills with peers, and to obtain multiple perspectives from others. Some studies reported positive relationships between online interaction and learning outcomes. Garrison and Cleveland-Innes (2005) claimed that cognitive engagement in online interaction was important for deep learning and meaningful educational experiences. Hou et al. (2007) suggested appropriate interventions for facilitating successful online discussion in PjBL, such as teachers' guidance and feedback, and standard discussion format. Liu and Tsai (2008) ascertained the pattern of peer interactions and important factors that influence online group activities. However, Chang (2008) reported controversial results regarding the role of online discussion on project work in university learning. In effect, the findings show inconsistency and unclear relationships between the use of online interaction and successful learning outcomes in PjBL. It suggests that further studies should be conducted to investigate the quantity and quality of online interaction and its relationship with learning achievements in PjBL.

2.2. Interaction analysis in online learning

Interaction is essential to meaningful learning experiences in face-to-face contexts as well as online environments (Garrison & Cleveland-Innes, 2005), given that the lack of social interaction in online learning environments may result in learning failure (Paloff & Pratt, 2001). Considering that deep learning and meaningful construction of knowledge can occur in interpersonal relationships and social activities in the view of socio-cultural learning (Barab, Thomas, & Merrill, 2001), the quantity and quality of interaction among participants must be of major interest in all educational settings. Interaction and engagement in online activities, such as online discussions, peer reviews, product development and knowledge building, provide online learners with continuing learning motivation and consummative experience toward further progress. Various opportunities and tools to facilitate interaction among participants should be provided for successful online learning (McLoughlin, 2002). Written communication through CMC is a powerful medium for exchanging ideas in online contexts (Garrison, Anderson, & Archer, 2000). Learners are able to have critical discourses and a worthwhile educational experience through message threads in online learning environments regardless of their diverse and dispersed perspectives. Schrire (2004) clarified the pattern of online interaction and its relationships with cognitive development in online discussion, and found the appearance of knowledge building in asynchronous online discussions. As the quality of online learning depends on the quality of interaction in most cases (Haythornthwaite, 2002; Jiang & Ting, 2000), more attention should be paid to the effective evaluation of the quality of online interaction.

The most popular way to analyze interactions in online learning is content analysis (De Wever, Schellens, Valcke, & Van Keer, 2006). Content analysis is a research technique for the objective, systematic, quantitative description of the manifest content of communication (Berelson, 1952, p. 519). One of the pioneers in the content analysis of online communication, Henri (1992) suggested a qualitative way to analyze content in terms of the participatory, cognitive, metacognitive and social aspects of interaction. Also, Garrison et al. (2000) developed a content analysis tool that examines three elements of educational transaction: cognitive, social and teaching presence. Gunawardena et al. (1997) proposed an analysis model to examine the social construction of knowledge in online interactions. Even though these tools were developed to analyze the quality of online interaction in CMC contexts, they are applicable when evaluating learners' interactions in online PjBL.

The qualitative analysis of content is often limited to specifying the quality of individual participation, which provides an understanding of the micro level of interaction. Thus, incorporating a network analysis focused on the relations among participants may offer better understanding of the structural pattern of online interaction (Lipponen, Rahikainen, Hakkarainen, & Palonen, 2002). SNA, a method for analyzing phenomena with quantifiable data, enables researchers to explore the relationships among participants in a macro perspective, rather than to focus on the individual attributes (Enriquez, 2008). This study employs both methods for investigating online interactions during project work in macro and micro perspectives: SNA will provide an overall pattern of online interaction in macro perspective, and content analysis with the existing tools will provide the qualitative features of online interaction in micro perspective.

3. Method

3.1. Participants

Forty-nine undergraduate students enrolled in an educational technology course at a woman's university in Korea participated in the study. Participants consisted of 32 sophomores, 8 juniors, and 9 seniors, mostly from the Department of Educational Technology. Only 10 of them were from other departments in the college of education. Participants were randomly assigned to small groups of seven, and the leaders of each team were also randomly assigned by the instructor.

3.2. Research context and procedures

The context of the study is an undergraduate course that explores the theoretical and practical approaches to instructional message design in e-Learning contents. This 16-week core course, basically, is delivered in a lecture-based classroom with selected online learning activities. Among the course activities, a three-week online project was chosen for this study. Although students were able to meet face-to-face, they were strongly encouraged to communicate online for the given project.

The learning goal of the online team project was to develop and apply a courseware evaluation framework and then to make instructional design suggestions for a specific educational content. The major activities that the students did in the online project were (a) naming of their own project teams, (b) planning to conduct the project, (c) developing an analysis framework, (d) analyzing educational contents with the framework and making recommendations for further development, and (e) writing a final report and creating presentation materials.

Although the class met face-to-face regularly, online bulletin boards were provided for the team project so the team members could communicate with each other at any time, wherever they were. In other words, each team shared ideas, information, and resources on its own bulletin board, which was provided by the learning management system (LMS) operated by the university.

The project began from the second week of October to the first week of November, 2008. The instructor of the course provided descriptions of the team project and randomly assigned students to groups. During the project, the instructor provided feedback and guidance according to the students' requests. Project scores were computed based on the instructor's evaluation and peer evaluation as well. The instructor developed a rubric for evaluating the process and the outcome of the project, and the criteria included, for example, understanding of the design principles, the applicability and creativity of the design suggestions, and so on. The project scores of seven teams were used for the selection of high- and low-performing teams for the content analysis, which relates to the second research question of the current study. The scores ranged from 20.1 to 27.3, and the possible maximum score was 30.

3.3. Data analysis

This study employed two different frameworks for interaction analysis: social network analysis (SNA) for analyzing interaction patterns among team members (macro level) and content analysis for analyzing messages shared within each team (micro level).

In general, SNA enables researchers to understand how individuals are connected within a network. In this study, SNA provided the perspective of group cohesiveness which examined the team network in terms of the presence of strong, direct, intense, or frequent relationships among team members (Scott, 2000; Wasserman & Faust, 1994). As an indicator of the group cohesiveness, density index of each group was calculated (Smith et al., 2008). By definition, the density of a complete network where every node is directly connected to every other node is 1, when the existence of ties is the only consideration (Lim & Kim, 2008). In this study, however, the question is 'who replied to whom for how many times', which involves direction as well as weight. Density index could be larger than 1 when both direction and weight are considered. Two different types of network were analyzed to compute density: response network and read network. The former counted the explicit interaction pairs consisting of a post and a reply, while the latter counted the number of pairs consisting of a post and a reading from the log data. The response network is considered more active than the read network, since posting a response to others requires overt action.

In addition, individual prominence was examined by the betweenness centrality, which measures the extent to which an individual lies on the paths between others (Freeman, Borgatti, & White, 1991). That is, individuals with high betweenness tend to have positional advantage, or power, to the extent that they fall on the pathway between other pairs of individuals. This study adopted flow betweenness among other betweenness centrality measures, since flow betweenness does not assume the shortest paths, but does assume proper paths in which no node is visited more than once (Borgatti, 2005).

Although SNA sheds light on the patterns of interaction in a clearer way, the analysis utilizes quantified data. As a way to analyze the quality of online interaction, a qualitative content analysis method, a model proposed by Gunawardena et al. (1997) was adopted for this study. It enabled us to examine the five levels of social construction of knowledge from sharing/comparing of information to applications of newly-constructed meaning. Table 1 presents a coding scheme employed for the analysis, including the five levels of knowledge construction and examples of raw data for each level.

Data were collected from the bulletin boards and log files after the team project work had been completed. The LMS automatically calculated the number of individual message postings and the pairs posted by participants. For the analysis of interaction patterns, the adjacency matrix for each team was developed and run by NetMiner 3.0.

For the analysis of the interaction content, four teams out of seven were purposively selected: two teams with the highest project achievement scores and the two teams with the lowest project scores. The unit of content analysis was the meaning, not the post, since messages of unequal length cannot serve as precise measures. At the initial stage of the coding process, all messages were analyzed by two coders according to the coding schemes in Table 1. Then the coders decided the major activities for knowledge co-construction, which were to construct the analysis framework, to evaluate online content and to make suggestions for improvement. The subsequent in-depth coding for the major activities was conducted by the two coders without any discussion. The inter-rater reliability was 86% agreement. During the coding process, if there were two or more paragraphs within a message with different codes, such messages were assigned two or more codes based on the order of the content (e.g., If the first section of a message belonged to the category P1 and the second and third sections belonged to the category P2, then the coding for this message would be P1 and P2). In case of disagreements, a single code was determined after discussion among the coders.

4. Results and discussion

4.1. Interaction patterns from the SNA

4.1.1. Frequency of interaction

Results of the analysis of participation and interaction frequency are shown in Table 2. The number of message postings reflects the total number of messages posted within each team, whereas the number of message pairs reflects the total number of ties generated by message postings and replies within each team. That is, a message does not necessarily mean an interaction when no one reads or reacts to this post. In this case, the post itself is considered a simple "participation" rather than an interaction (Lim & Kim, 2008). Therefore, counting the number of messages in an online discussion is more like analyzing individual participation. After all, participation is necessary but not sufficient to interaction, which exists only when student A posts a reply to student B.

The number of message postings differed among the seven teams, as shown in the descriptive statistics in Table 2, ranging from the 91 of Team D to the 282 of Team C. Regarding the number of message pairs in the response network, Team C had the most frequent interaction pairs (211 pairs), followed by Team G (134 pairs) and Team B (122 pairs). In the read network, on the other hand, Team C had the highest (1394 pairs), followed by Team B (1119 pairs), and Team A (1026 pairs). It is clear that interaction in terms of reading is more frequent than interaction in terms of responding (The mean of the number of pairs in the response networks = 105.14; the mean of the number of pairs in the read network = 968.00).

4.1.2. Patterns of team interaction

Regarding the first research question, SNA revealed the pattern of interaction within each team, as visualized in Table 3. The direction of the arrows reflects the direction of interaction between the two team members, and the thickness of the lines reflects the strength of the

Table 1
The coding schemes based on the interaction analysis model by Gunawardena et al. (1997).

Code	Phase	Indicator (examples only)	Raw data (examples only)
P1	Sharing and comparing of information	Presenting new information to team members	"I uploaded the first version of the analysis framework. Please give some feedback, and add your opinions"
P2	The discovery and exploration of dissonance or inconsistency among ideas, concepts or statements	Asking and answering questions to clarify the source	"Do we need to focus on the motivation theory for the analysis framework?"
P3	Negotiation of meaning/ Co-construction of knowledge	Negotiating the meaning of terms	"Well, I think no. 1 criteria will be merged with no. 4. What you think of?"
P4	Testing and modification of proposed synthesis or co-construction	Testing against personal experience	(n/a)
P5	Agreement statement/applications of newly-constructed meaning	Accepting and applying new idea	"Ok. I will accept and revise according to your comments"

Table 2
Frequency of participation and interaction.

Team	Number of team members	Number of postings (Participation)	Number of pairs (Interaction)	
			Response network	Read network
A	7	192	76	1026
B	7	204	122	1119
C	7	282	211	1394
D	7	91	35	484
E	7	156	86	856
F	7	166	72	906
G	7	231	134	991
Mean		188.86	105.14	968.00
SD		60.37	57.09	276.53

interaction. A team with more links among the members presents more stable polygon. For example, Team A's total interaction network, which is an addition of response network and read network, implies that the team members are fully connected in all directions. They created 49 links, which are exactly the maximum possible links within each team when there are seven members sharing two-way interaction. On the other hand, Team B's response network presents different shape due to the missing links among some members. Small circular arrows near each node indicate that they posted messages in response to their own postings. Each node has its unique shape and color across different types of networks in order to identify who is who more easily. Along with the visualizations, the numbers of links as well as the density index of each team are also presented.

According to the results in Table 3, response networks are visualized as less dense than read networks as indicated by thinner and fewer links. Among the seven teams, Team C showed the highest group cohesiveness in terms of the total interaction network (density index = 30.00). More specifically, Team C scored a density index of 4.48 in the response network and 25.69 in the read network. The members of Team C had frequent two-way interactions with each other, where the information flowed freely in the network. On the other hand, Team D showed the lowest group cohesiveness (density index of the total network = 9.81; density index of the response network = 0.74; density index of the read network = 9.36). In particular, Team D had 22 links among seven team members in the response network, meaning that information may not have flowed freely as overt interaction. In sum, the number of postings and the number of message pairs tend to correlate, based on the seven teams' results. The more participation occurred, the more interaction there was among team members.

Regarding the individuals in each team, students with high prominence in the response network tend to have a similar position in the read network. However, there are a couple of students who show different patterns. For example, ■ in Team B is connected with only 2 members in the response network, while she shares thick links with 5 members in the read network. In other words, the student may have posted many messages, but she failed to generate interaction since she did not receive responses from others. Further investigation of the number and content of her postings revealed that she posted 14 messages in total (6.8% of the postings made by Team B), and 12 of them were postings initiating a new thread not replying to others, while only 2 of them were responses to others. Most of the contents focused on sharing the work she did. On the other hand, ● in Team E has relatively stronger individual prominence in the read network than in the response network, receiving attention from others. After examining her interaction patterns, it was found that she posted 19 initiating posts in addition to 23 replies to others, totaling 42 posts (26.9% of the postings made by Team E). Her messages covered various topics from sharing her work to encouraging others.

Another measure illustrating individual prominence is betweenness centrality. Table 4 presents the average of each individual's flow betweenness within a team, ranging from 7.86 (Team D) to 49.29 (Team C) in the response network. Interestingly, the standard deviations of Teams A, B, E, and F varied from the minimum of 8.28 (Team A) to the maximum of 32.79 (Team C), although the average scores of these four teams were quite similar. That is, individuals in Team A shared a similar level of prominence in the network, whereas individuals in Team B had very different levels of prominence in the network. In other words, information flow may have been centralized by only a few. Regarding the read networks, Team F had the lowest standard deviation ($M = 194.57$, SD = 40.76), and Team G also showed a relatively low standard deviation ($M = 179.29$, SD = 93.66), compared to Team B ($M = 188.86$, SD = 159.72). All in all, the density index and the average of flow betweenness together yield noticeable results: Team F had a density of 16.64 which is rather low among the seven teams, but the individuals in the team shared a relatively similar level of prominence. On the other hand, Team C showed the highest density among seven teams (density index of Team $C = 30.0$), but there were a couple of individuals who had strong prominence in the network.

4.2. Social construction of knowledge from content analysis

Content analysis was employed to understand how learners interacted with others and constructed new knowledge during project work, referring to the second research question. In order to select the teams to be analyzed, the project score of each team was used, and two high-performing teams (Team F: 26.4; Team G: 27.3) and two low-performing teams (Team C: 21.2; Team E: 20.1) were finally chosen.

Based on the coding scheme illustrated in Table 1, the level of social construction of knowledge presented by the high-performing teams (F and G) and low-performing teams (C and E) was analyzed in Fig. 1. Overall, team members in Team F and G not only shared information (Phase I), but also identified the areas of disagreement and clarified the goals and strategies (Phase II). They also conducted negotiations and achieved the co-construction of knowledge (Phase III). However, team members with low scores (Team C and E) shared information and stated their opinions in most cases (Phase I). On the higher level of social construction, not much occurred in the two teams with low performance. Interestingly, no testing and modification of proposed syntheses or co-construction (Phase IV) occurred in any of the teams.

It is notable that Teams F and G produced 39.3% and 25.9%, respectively, of Phase III messages, while Teams C and E produced only 4.3% and 5.9% (see Fig. 1). To illustrate, teams with high scores conducted more negotiation and achieved more co-construction of meaning

Table 3
Interaction patterns visualized by SNA.

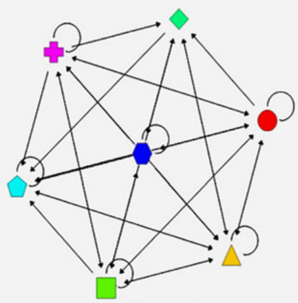
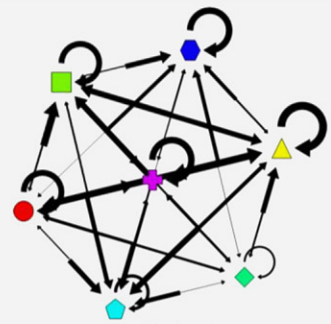
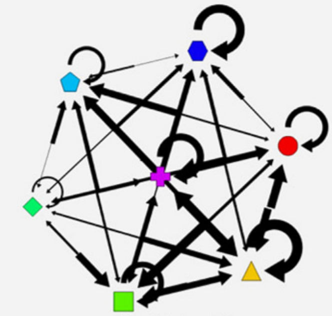
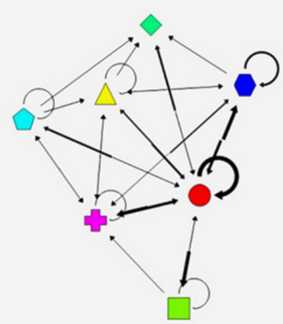
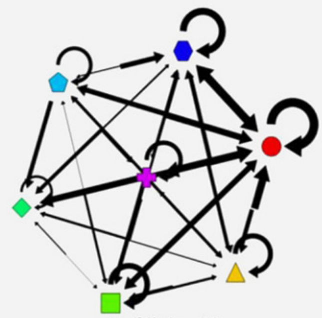
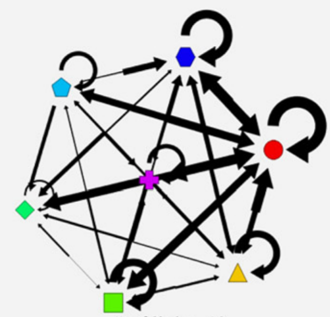
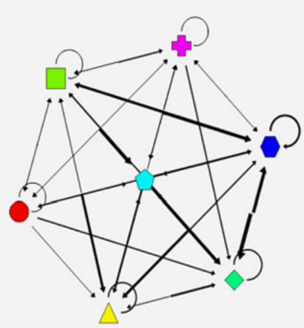
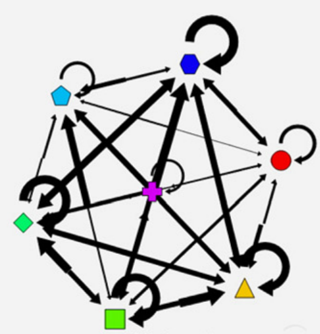
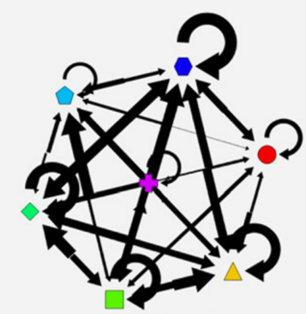
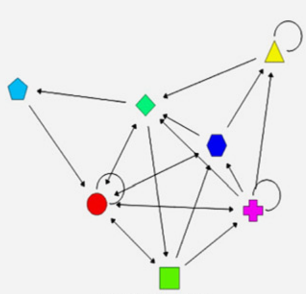
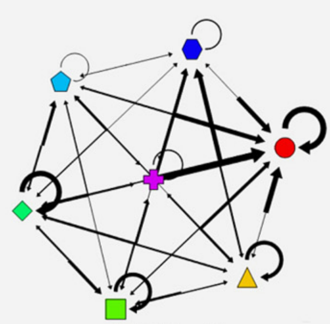
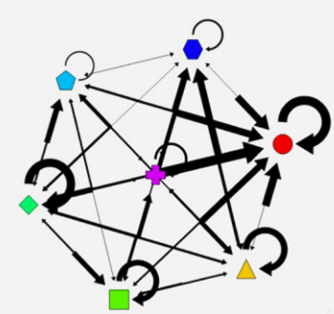
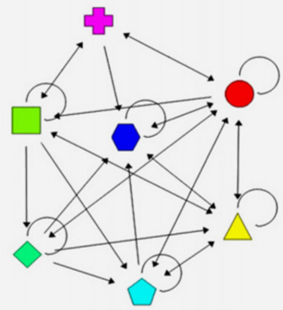
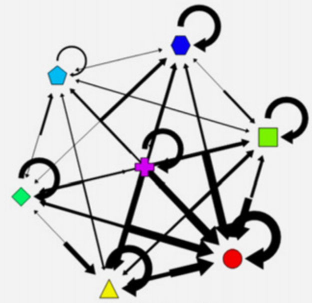
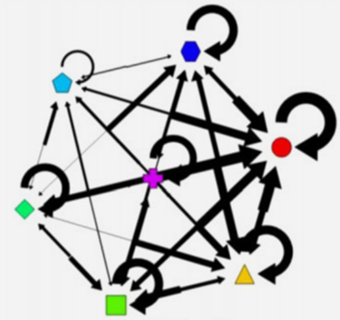
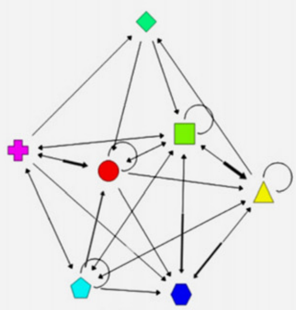
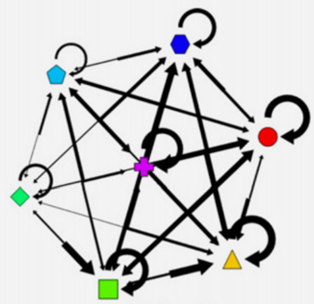
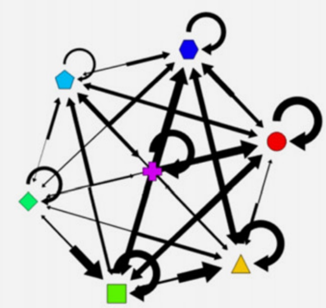
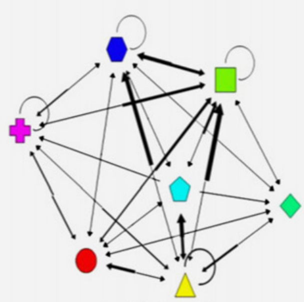
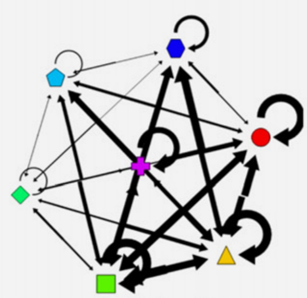
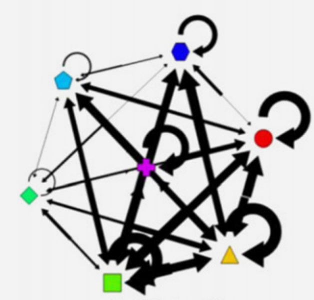
Team	Response network	Read network	Total interaction network
A	 # of links=37 Density=1.57	 # of links=49 Density=19.88	 # of links=49 Density=21.41
B	 # of links=31 Density=2.19	 # of links=48 Density=19.19	 # of links=48 Density=20.07
C	 # of links=43 Density=4.48	 # of links=49 Density=25.69	 # of links=49 Density=30.00
D	 # of links=22 Density=0.74	 # of links=49 Density=9.36	 # of links=49 Density=9.81

Table 3 (*continued*)

Team	Response network	Read network	Total interaction network
E	 # of links=32 Density=1.71	 # of links=48 Density=15.17	 # of links=48 Density=16.81
F	 # of links=31 Density=1.57	 # of links=49 Density=15.71	 # of links=49 Density=16.64
G	 # of links=42 Density=2.98	 # of links=49 Density=18.17	 # of links=49 Density=20.90

among team members, while teams with low scores conducted fewer negotiations and less co-construction occurred. For example, Team E had 56.6% of Phase I and II, and then had 39.1% of Phase V, meaning that Team E mostly shared information and then moved right on to the "agreement statements" with little negotiation of opinions among participants. In contrast, Team G exchanged more messages related to Phase III (39.3%), indicating that students in Team G spent more time negotiating meanings and co-constructing new perspectives. The students in the low-performing teams experienced knowledge sharing which is mainly transmitting information to each other. However,

Table 4
Average flow betweenness centrality of teams.

Team	Flow betweenness of response network		Flow betweenness of read network		Flow betweenness of total interaction network	
	M	SD	M	SD	M	SD
A	17.43	8.28	257.00	72.29	280.86	72.11
B	17.14	26.43	188.86	159.72	188.86	174.89
C	49.29	32.79	294.57	124.17	337.86	145.66
D	7.86	5.61	102.86	33.37	107.86	40.55
E	17.43	16.93	139.14	65.47	158.29	75.46
F	14.14	6.77	194.57	40.76	187.71	39.86
G	27.57	10.69	179.29	93.66	210.00	110.76

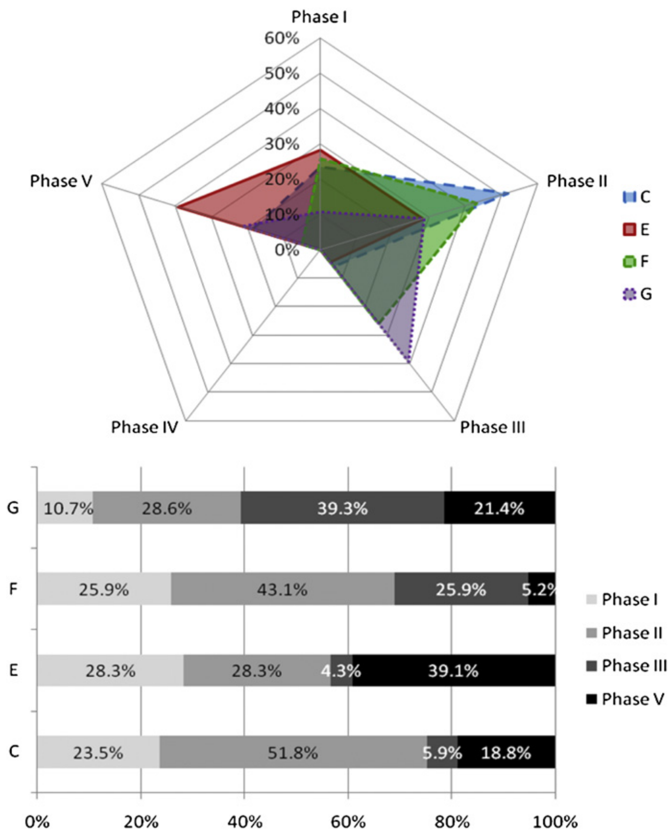


Fig. 1. Results of content analysis using the model of Gunawardena et al. (1997).

the students in high-performing teams had chances to reflect their knowing and reconstruct the existing knowledge for their project, referring to knowledge construction.

For the in-depth understanding of online interaction, the messages posted on online discussion boards were analyzed. First of all, most messages exchanged in low-performing teams (teams C and E) referred to 'providing feedback' and 'revising the original with the given feedback'.

Student C-1: I developed a draft checklist to analyze an e-Learning content. There are main categories and each category has its sub items. I suggest the recommendation for revision should be described separately from the results of analysis. What do you guys think?
Student C-2: I agree with C-1's idea on the checklist. I just added some criteria and scales of the analysis.
Student C-1: Good job! Thanks.
Student C-3: I would like to suggest that the No. 1 and 2 in Socio-psychological aspects (the fifth domain) should be incorporated into the first domain, and the title of the fifth domain needs to be changed as Social aspects.
Student C-4: I like C-3's suggestion. Let's do it.

Probably, the task was not challenging enough to elicit active discussion from them. However, evidence of deep discussion of the task was found in messages exchanged in high-performing teams (teams F and G).

Student G-1: I uploaded a framework of analysis in terms of motivation theory in learning on our online boards. Please give me any advice or feedback on this. Any revisions directly on the framework are welcomed!
Student G-2: I appreciate your effort. You must have spent lots of time. I posted my opinions about the framework. Please take a look at my feedbacks and questions, and let me know your thoughts. (For example, No. 9 is to use personal terms in learning contents. If it is a principle related to text display, it might be merged in No. 23. Even the use of a literary style and typology in No. 23 is a bit mixed up with No. 11, which is about the use of language).

Student G-1: Thanks for G-2's feedbacks. Here is my thought on yours. In No. 9, using personal terms in learning processes is originally included in the motivational theory in learning. Think about it as a personalized principle. In No. 11 and 23, I thought the language means vocabularies and words. If the literary style is interpreted as the way of talking, it might be liked to each other. Let's discuss this issue all together.
Student G-3: We discussed about G-1′s suggestions together as a sub-team. We decided to use accurate expressions, for example, using typology instead of language.

As shown in the above messages, the high-performing teams F and G spent time clarifying ideas, negotiating meaning and combining ideas for better performance. Throughout the discussion, they engaged deeply in reflective thinking and then developed the best solution as a result of the social construction of their knowledge. This process was critical for them to be successful in project work. As mentioned in the study of Garrison and Cleveland-Innes (2005), a deep approach to learning results in better outcomes in PjBL. Pointing out the importance of knowledge construction in online interaction (Gunawardena et al., 1997; Thomas & MacGregor, 2005), social activities during knowledge construction with team members lead them to obtain higher achievements in project work. This study, at first, assumed that active interaction among team members was important to be successful in PjBL. However, Team C, which had the highest interaction during online discussions, achieved a relatively low score for the project outcome. Team G that had a relatively low density of interaction during online discussions gained the highest score. The difference between two groups is related to how well learners engaged in terms of social interaction and construction of knowledge.

5. Conclusions

This study investigated how online interaction in PjBL is influential in obtaining successful learning performances. As peer interaction is critical in face-to-face learning contexts, interaction among participants online may also be essential in PjBL. Regarding the overall patterns of online interaction in project teams analyzed by SNA, it was revealed that each team had a different frequency of read and response networks, and patterns of online interaction. Team C had the most frequent online interaction with high group cohesiveness during project work. It confirmed that high interaction affects communication, mutual support and cohesion within team members (Guzzo & Dickson, 1996; Hoegl & Gemuenden, 2001). However, surprisingly, the team got the lowest score on the team project, which is different from the findings from other studies that reported the positive effect of online interaction on learning performance (e.g., Lim & Kim, 2008; Schrire, 2004). Content analysis explained this unexpected result. Compared to the team with the highest project performance, most interaction among the members of Team C related only to information sharing and accepting new ideas with little discussion. They engaged in the lower levels of cognitive processes and then ended up with less successful outcomes (Zhu, 2006). As mentioned earlier, this result implies that meaningful learning can occur through the co-construction of knowledge and conjoint actions with peers in PjBL.

Apparently, a certain amount of online interaction is a necessary factor for carrying out team project work these days, but the quality of online interaction is critical for successful outcomes in PjBL. Even the quantity of online interaction, in itself, does not guarantee the quality of online interaction for a desirable experience in online learning. Based upon the findings, the following aspects should be taken into account in further studies.

First, learning supports should be provided for enhancing the quality of online interaction in PjBL. To provide learners with guidelines for engaging in the process of knowledge construction is one way to support them online. Also, the visualized information on interaction patterns and individual prominence in relations with others through network analysis will provide both teachers and students with opportunities to reflect on participation and interaction in collaborative work. Another way to support learners may include resources and tools used by learners, and the teaching strategies employed by teachers. Learners may face some difficulties, such as managing their time, understanding the scope of the project, locating resources, reflecting on their ideas with peers, setting priorities, and co-constructing products during project work. To overcome these, teachers and online tutors need to track learning processes and provide adaptive support and feedback in appropriate ways.

Second, the complexity of project topics may also be a critical component for achieving the social construction of knowledge in project work. In this study, students worked on constructing an analysis framework and applying it to real settings as sub-tasks. Interestingly, most interaction for co-construction of knowledge appeared in constructing the analysis framework which may involve learners in higher-order thinking processes, compared to the other sub-task of applying it to real settings. When individuals work in more complex and ill-structured contexts, they might have more chances to experience proficient interaction with their peers and deep learning in online learning settings. In this case, teachers need to be aware of keeping learners on the right track, because learners often waste too much time figuring out the project scope in a limited time frame, and fail to obtain desirable outcomes.

Further research should be conducted to broaden the understanding and address the limitations of this study. First, the source of data in this research was limited to asynchronous online discussion threads only. Given that students were able to talk via face-to-face or synchronous chatting, various methods to capture other forms of interaction should be considered. For example, researchers may ask students to save chatting texts, or keep detailed journals for the meetings. Second, the social construction of knowledge was examined based on Gunawardena et al. (1997) in this study. As a follow-up, a framework for the content analysis may vary. For example, emergent coding may provide interesting perspectives, when several students with high individual prominence are selected and examine how they contributed to the discussion. Third, rooted in the conclusions and implications of this present study, further research will elaborate the guidelines for the successful project-based learning. Since the results of this study are limited to a specific, small group of participants as well as to the context of online project environment where online interactions may reflect partial group performance only, and furthermore, since the nature of the research questions is descriptive, caution is necessary when generalizing beyond the scope of this study.

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