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Student-Facilitated Online Discussions to Encourage Critical Thinking in Civil Engineering

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Abstract

Engineering education is heavily based on mathematical equations and laboratory experiences which makes it difficult to teach online as compared to other disciplines. This leads to many engineering educators to choose lecture capture—streamed and/or recorded— as a way to serve distance education students. However, this approach fails to make use of the capabilities of quality online learning and fails to engage distance education students. To address this concern, an online graduate level civil engineering course was redesigned to increase interaction amongst students and engagement in the material which in return would encourage critical thinking. Through social networking analysis and content analysis approaches, this study aimed to explore patterns of interaction and level of critical thinking during student-facilitated online discussions. Analysis of the results indicated that online discussions increased interaction amongst students and contributed to students' critical thinking skills.

Engineering education is heavily based on mathematical equations and laboratory experiences which makes it difficult to teach online as compared to other disciplines [1]. This leads to many engineering educators to choose lecture capture—streamed and/or recorded— as a way to serve distance education students. However, this approach does not make use of the capabilities of quality online learning and fails to engage distance education students [2]. To address this concern, an online graduate level civil engineering course was redesigned to increase interaction amongst students and engagement in the material which in return would encourage critical thinking. This study aimed to explore patterns of interaction and level of critical thinking during student-facilitated online discussions through social networking analysis and content analysis approaches. Making online discussion an effective learning tool requires an effective activity design and facilitation [3]. Therefore, it is necessary to explore how to design an online discussion activity to maximize the potential of this strategy in fostering critical thinking in engineering context, which is limited in the current literature.

Critical thinking in engineering education and online discussions

Critical thinking is an important graduate attribute and a common objective of various disciplines and engineering is not an exception [4], [5]. [6] defined critical thinking as “a dynamic activity, in which critical perspectives on a problem develop through individual analysis and social interaction” (p. 4). This definition highlights the link between critical thinking, social interaction, and deep learning that social interaction can promote deep learning which requires a critical understanding of the material.

In particular, critical thinking is foundational to engineering education and to engineering practice in solving engineering problems, designing products, systems or processes [7]–[9]. With higher levels of critical thinking skills, engineering students should be able to state a problem clearly and break it into sub-questions; identify their assumptions and determine whether they are justifiable; gather sufficient information and avoid unsupported conclusions; and use clear, accurate, and relevant information [8]. However, previous research indicated that engineering educators focused more on content coverage rather than creating learning opportunities for practicing critical thinking skills [4]. Learning activities that stimulates critical thinking skills would be desirable in any engineering classroom.

Online discussion has emerged as a promising method for encouraging critical thinking in distance education [5], [10]. It provides opportunities for flexibility [11], [12] and collaboration [5]. Asynchronous text-based mode allows for greater reflection and higher levels of critical thinking and in-depth feedback as well as allowing instructors to model, foster, and evaluate the critical thinking skills exhibited during the discussion [6], [11], [13], [14].

Despite the potential of online discussions in promoting critical thinking, instructors may tend to focus students' efforts on knowledge retrieval and lower level thinking [10]. For example, McLoughlin and Luca [15] examined students' discussion participation in a project management course and reported that most of the forum messages fell into the "comparing and sharing information" category, which indicated that the forum did not appear to foster critical thinking. This indicates that utilizing online discussion as an effective learning tool to promote critical thinking requires effective learning design and facilitation [3].

Instructor-facilitated versus student-facilitated discussions

Instructor-facilitated discussion has been used in both face-to-face and online formats. Instructor facilitation and scaffolding have been identified by many scholars as crucial for fostering high-level thinking within online discussions. Arend [10] examined students' use of critical thinking strategy in online courses across disciplines and suggested that critical thinking appeared to be best encouraged when instructor facilitation was less frequent but more purposeful, continually provoking students with selectively spaced, neutral, probing questions. Faculty can scaffold students also by modeling questioning techniques that promote critical thinking [16]. Similarly, Yang [17] indicated that online discussions can help students become independent critical thinkers if the instructor plays a pedagogical role in teaching, modeling, and prompting Socratic dialogues.

However, instructor facilitation may result in an instructor-centered discussion which limit students' participation and voice [18], and student-facilitated discussions provide an alternative approach. Peer facilitation can foster a sense of student ownership and help students feel more at ease in expressing their opinions [19], and allow practical hands-on experience of being a discussion facilitator [18]. Compared to instructor-facilitated discussions, research on student-facilitated discussions is still limited focusing more on the student facilitation techniques [11], [20]. This study aims to explore how overall design and management of student-facilitated discussions influence peer interaction and critical thinking in engineering education context. Following research questions guided this study:

1) How do student-facilitated asynchronous online discussions effect peer interaction in a graduate level engineering course?
2) How do student-facilitated asynchronous online discussions effect critical thinking in a graduate level engineering course?

Methodology

Research context

Preconstruction Project Engineering and Management is a required course for the Construction Engineering and Management specialization in a civil engineering department at a large Midwestern university of USA. The goal of the course is to provide students with an understanding of construction complexity and change in project management skills. Main course tasks included watching pre-recorded lectures, reading research papers, participating in group discussions, working on a group case study project, and writing an individual reflection paper.

As the major task for the course, online discussions required students to discuss the course concepts every week. There were two whole-class and ten small group discussions. The instructor led the first whole-class discussion to model facilitation strategies. The students were purposefully assigned to small discussion groups based on their background (i.e. work experience, distance education vs. on-campus). Each student signed up to facilitate a group discussion twice. The discussion leaders of each group chose one reading from the suggested list of readings for group members to read. The discussion leaders were expected to post three to four questions based on the selected reading; keep the discussion moving by posting follow-up questions and comments; and provide a summary of the discussion at the end of each week. All remaining members were required to post one original response and at least two comments to each of the discussion questions.

Data collection and analysis

Data gathered for this study were the discussion messages posted on the discussion forums on the course management system, Blackboard by twenty students who were enrolled in the course during fall 2015 semester on. More than half (13) of the students had some work experience in the field either as full-time employees or interns.

Social network analysis (SNA) method was used to examine connectedness and peer interaction. SNA helps identifying patterns of relationship between members of a social network by unveiling the flow of communication and how participants interact with each other and provides an indication of the level of group cohesion [21]. All the discussion forum posts were included in the social network analysis. Socnetv—an online social network analysis software—was used to examine the network cohesion, to calculate network density, and to create a sociogram to display the interaction patterns. *Network density* refers to number of communicative links observed in a network divided by the maximum number of possible links, and it ranges from 0 to 100% [22], and a high network density means a connected community. To examine the group balance degree centralization, out- and in-degrees were calculated. A high degree centralization value refers to situations where interaction is dominated by certain group members [21]. Out- and in-degree values display the number of messages each participant sent out and received.

Content analysis method was used to explore the use of critical thinking skills by coding the transcripts of the online discussions in unit of meaning, which means that a statement coded as at least one indicator could be a phrase, a sentence, a paragraph, or a message as long as it contains one unit of meaning. The unit of meaning was also utilized when quantifying the qualitative data and calculating the critical thinking ratio.

Three discussion forums in each group were selected for content analysis to represent one early-semester discussion (week 3), one mid-semester discussion (week 7), and one late-semester discussion (week 13 to examine and compare the students' use of critical thinking over the course of a semester.).

The discussion posts were coded for emerging themes and categories based on a coding scheme adapted from Newman at al. [6] using a qualitative data analysis software application, NVivo. The coding scheme included five categories of critical thinking: novelty (N), outside knowledge (O), linking (L), justification (J), and critical evaluation (C). Table 1 displays the categories, descriptions and example quotes. Each category included positive and negative indicators of critical thinking. Critical thinking ratio for each indicator was calculated based on the following formula:

$$\text{Critical thinking ratio} = \frac{\text{Number of positive indicators} - \text{Number of negative indicators}}{\text{Number of positive indicators} + \text{Number of negative indicators}}$$

Table 1. Coding Scheme for Critical Thinking

Category		Indicators	Example quote
Novelty	N+	Provide new opinions/ ideas/ information/discussion questions that have never been mentioned	And from my observation over a year, I think the mental pressure was the critical reason for low productivity (G3 W7)
	N-	Repeat what has already been said without any further exploration	Like you have pointed out, there are things that are beyond our control but still, plan can be made for those too. (G1 W13)
Outside knowledge	OE+	Draw on personal experience	Since my father is a contractor, I have seen him placing bids for the project which is within his capacity and not beyond the limit (G2 W 3)
	OC+	Critique/interpret/ cite course materials (reading. lecture, previous discussion)	Like stated in the article, the codes typically exist for most things (some are relatively new like LEED) but only provide guidelines and don't consider ever single possibility. If that was the case, there wouldn't be a discrepancy in the amount of true incidents versus what the codes predict there will be. (G1 W7)
	OK+	Use prior knowledge, observation	I had a guest lecture [in another class]. It was about replacing a bridge. There they replaced it half a bridge at one time. Because there was no other way to cross the river. (G3 W13)
	OM+	Use outside materials	This paper (providing a link) suggests that uncontrollable risks associated with the project must be identified and the cost effect of each risk factor should be assessed in detailed for providing realistic cost estimates. (G4 W3)
	O-	sticking to prejudice or assumption	Not observed
Linking	L+	Linking facts, ideas and notions/ making inferences/evidence of interpretation (Include ask peer to clarify opinion or information)	I believe in order to produce uniform and consistent estimate, the estimator is going to need a reliable database from which to extract labor productivity factors, labor rates, equipment costs, insurance costs, tax rates, subcontractor unit prices, and material costs. (G2 W3).
	L-	Repeating information without making inference or offering an interpretation OR stating that one shares the ideas or opinions stated, without taking these further or adding any personal comments	The location can also be a factor as you mentioned. (G3 W3)
Justification	J+	Justify opinion, agreement, disagreement with supporting reasons/ examples /proof OR setting out advantages and disadvantages of situation or solution	If the project is complex and requires a huge amount of attention so as to minimize the risk, then planning oriented approach is necessary as it will help in forecasting uncertainties of future complexities and can minimize it to a great extent (G4 W13).
	J-	Offering opinion or judgments without explanations or justification	I think the mental pressure was the critical reason for low productivity (G3 W7).
Critical evaluation	C+	Critical assessment/evaluation of own or other's' contribution toward the issue discussed	That was a good point made by you on the bidding technique carried in your friend's company to earn more profit. Nowadays this technique is widely used by all the construction industries which is called as "Unbalancing the bid" technique (G2 W3).
	C-	Uncritical or unreasoned acceptance /reject	I support your idea that effective new techniques come from innovation which could result a new method to manage a project (G1 W13).

Results

Patterns of interaction and connectedness

Students in this study participated in one whole class discussion, and then they were placed in small groups for the upcoming topic discussions. The whole class discussion was used to model facilitation strategies and introduce students the logistics of online discussions. The purpose of small group discussion was to provide students with an opportunity to engage in an in-depth discussion of a given topic through back and forth messaging. When the interaction patterns were analyzed, it was noticed that small groups had a higher network density (100%) than the whole class discussion (24%). The relatively low density in the whole class discussion indicated that not all members interacted with every single group member (Figure 3).

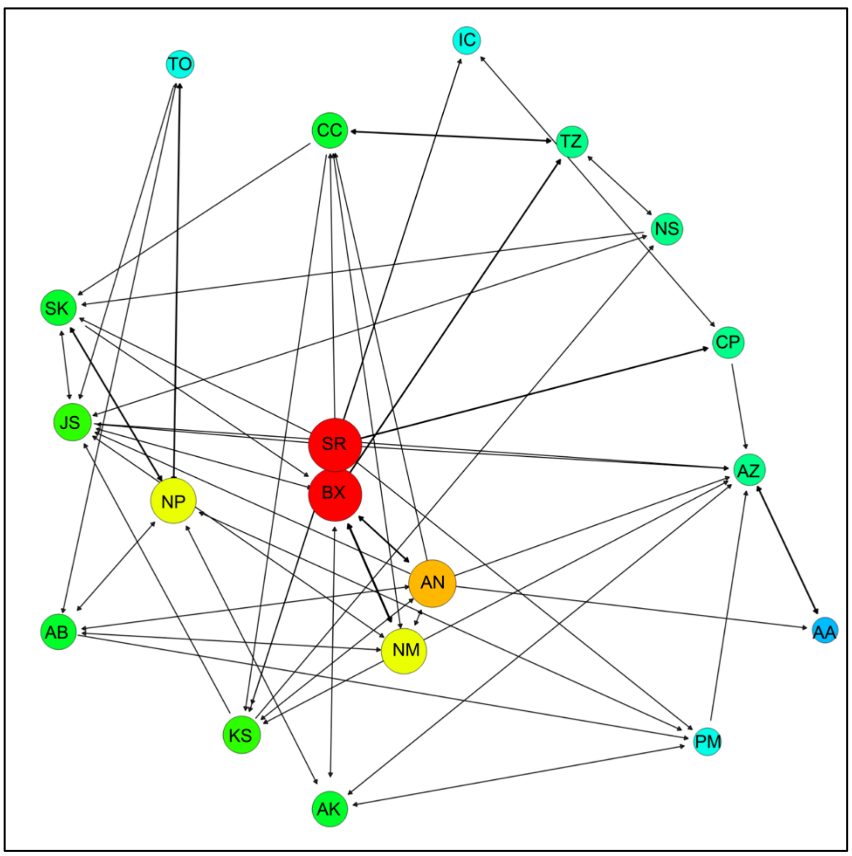

Figure 1. Interaction patterns between participants in a whole-class discussion

A high-density level in small groups indicated that members of the groups were closely communicating with each other. Every member of the group interacted with every other member of the group throughout a ten-week discussion task (Figure 4).

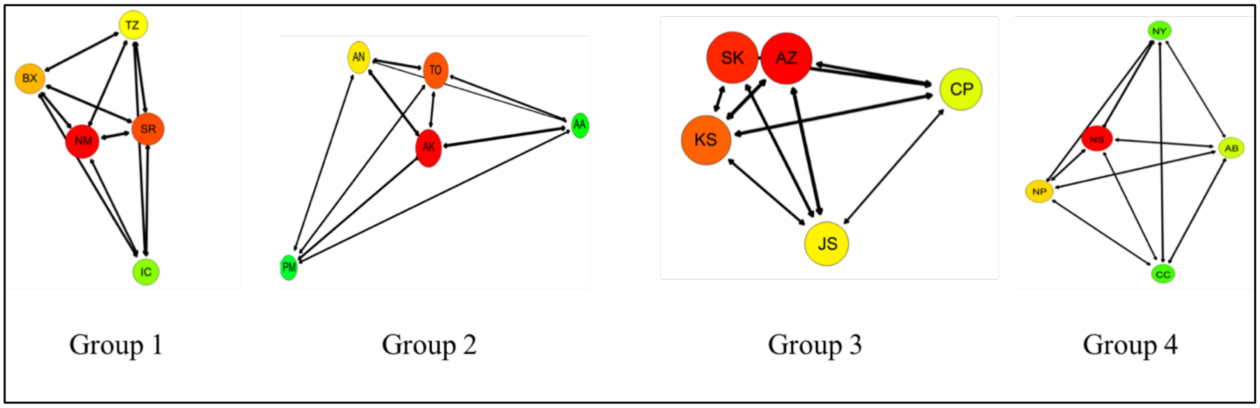

Figure 2. Interaction patterns between group participants in a 10-week long small group discussion led by students

To examine the group balance degree centralization, out- and in-degrees were calculated. In small group discussions, when aggregated results for all ten weeks were considered, there did not appear to be a participant who dominated the discussions. Rather, they all equally contributed. In the whole class discussion, on the other hand, degree centrality values implied that three students (SR, BX, AN) dominated the discussion (Table 2).

Critical thinking and online discussions

The second research question aimed to further delve into the content of online discussions and examined how they affected students' critical thinking skills. Table 3 displays the number of indicators for each category of critical thinking in units of meaning. It is clear that positive indicators outnumbered the negative indicators for all five categories implying that students were engaged in critical thinking more so than non-critical thinking.

Table 2. Degree centralization, and out- and in-degree values for each participant

Participants		Degree Centralization		Small Group		Whole Class	
Group	Participant	Small Group	Whole Class	Out-Degree	In-Degree	Out-Degree	In-Degree
Group 1	SR	0.224	**0.500**	96	130	11	5
	IC	0.154	0.167	66	70	3	3
	NM	0.242	0.278	104	81	8	8
	BX	0.198	**0.333**	85	76	11	12
	TZ	0.182	0.167	78	72	4	6
Group 2	AA	0.135	0.056	40	55	2	3
	AK	0.276	0.222	82	88	5	4
	PM	0.125	0.167	37	42	3	5
	AN	0.212	**0.444**	63	63	9	7
	TO	0.253	0.167	75	49	3	3
Group 3	CP	0.166	0.167	36	38	4	6
	JS	0.175	0.278	38	43	6	8
	KS	0.207	0.278	45	47	6	5
	SK	0.221	0.167	48	37	5	6
	AZ	0.230	0.167	50	52	4	10
Group 4	AB	0.192	0.278	42	53	5	4
	CC	0.155	0.222	34	31	5	4
	NP	0.215	0.278	47	53	8	7
	NY	0.274	0.167	60	40	4	3
	AY	0.164	*	36	42	*	*

* this participant did not participate in whole class discussion

Table 3. Number of critical thinking indicators for each category in units of meaning

Group	Week	N+	N-	OE+	OC+	OK+	OM+	O+	O-	L+	L-	J+	J-	C+	C-
Group 1 5 students	W3	31	4	18	2	5	2	27	0	21	6	23	2	20	15
	W7	40	4	24	7	3	5	39	0	15	4	22	1	31	5
	W13	26	3	11	10	1	3	25	0	13	2	21	4	22	10
Group 2 5 students	W3	30	0	2	2	10	2	16	0	8	0	16	2	9	3
	W7	13	0	3	1	3	17	24	0	10	0	12	1	3	3
	W13	23	1	3	1	0	4	8	0	6	1	19	1	6	2
Group 3 5 students	W3	34	0	1	6	1	10	18	0	8	1	19	3	11	3
	W7	26	0	8	1	5	4	18	0	6	0	19	5	6	1
	W13	10	0	5	0	2	2	9	0	1	1	2	2	9	2
Group 4 5 students	W3	41	1	1	3	4	5	13	0	11	0	26	3	8	0
	W7	21	0	0	5	2	10	17	0	6	1	11	1	8	2
	W13	24	0	0	2	3	5	10	0	5	0	27	0	15	2
Total		**319**	13	76	40	39	69	**224**	0	**110**	16	**217**	25	**148**	48

Table 4 displays the critical thinking ratio for each category. Of the five categories, novelty seemed to be the one with the highest number of units of meaning (319 total) indicating that students provided a new opinion, or information often, and the average critical thinking ratio was 0.94 with a standard deviation of 0.09. In this study, students seemed to bring in novel information mostly in their initial posts, where they provided answers to the discussion leaders' questions and when participants asked follow-up questions. For example, in week 3, group 1 discussion leader provided a summary of cost estimating principles, and asked group members if they knew any other cost estimates. One student commented about how location affects the cost. As a follow up, another student wrote "The location policy, the regulations, the available facilities and resources—all are considered. And this is not only to maximize the profit but to make sure the estimate generated suits the nature of the project" (G1, W3).

Table 4. Critical thinking ratio of each category of critical thinking in each discussion forum.

Group	**Week**	**N Ratio**	**O Ratio**	**L Ratio**	**J Ratio**	**C Ratio**
Group 1	W3	0.77	1.00	0.56	0.84	0.14
	W7	0.82	1.00	0.58	0.91	0.72
	W13	0.79	1.00	0.73	0.68	0.38
Group 2	W3	1.00	1.00	1.00	0.78	0.50
	W7	1.00	1.00	1.00	0.85	0.00
	W13	0.92	1.00	0.71	0.90	0.50
Group 3	W3	1.00	1.00	0.78	0.73	0.57
	W7	1.00	1.00	1.00	0.58	0.71
	W13	1.00	1.00	0.00	0.00	0.64
Group 4	W3	0.95	1.00	1.00	0.79	1.00
	W7	1.00	1.00	0.71	0.83	0.60
	W13	1.00	1.00	1.00	1.00	0.76
Average (SD)		0.94 (0.09)	1.00 (0.00)	0.76 (0.29)	0.74 (0.26)	0.54 (0.27)

(N: novelty, O: outside materials/experience, L: linking ideas, J: justification, C: critical evaluation)

The quote exemplified how students built upon each other’s ideas and comments, brought in new perspectives and carried the discussion forward. Sparingly, students made comments simply repeating and agreeing with the previous statement without making additional comments such as “you have focused upon a very important issue”, “I was in the same situation”. Those comments; however, still helped students acknowledge each other’s contribution; and create a sense of community.

The following category was outside knowledge, which was split into subcategories of personal experience, course materials, prior knowledge and outside materials. The critical ratio of this category was 1 across all forums, which indicated that the students actively brought personal experiences and outside resources during the discussion. The grading rubric, which asked students to use references to literature, readings, or personal experience to support ideas and opinions, might have encouraged this.

The diverse background of the student body in this study might have also contributed to frequent use of this category of critical thinking, especially drawing on personal experience. The students had working experiences in different countries, which allowed them to see differences between countries. Students with little industry experience also benefit from other’s experience sharing, as one student stated, “I can get to know a lot about the other countries’ construction industry, their situations, and solutions for the errors they make by the personal experience you guys have.” (G1 W7).

The next category was linking which referred to statements when a student linked facts, ideas and notions; made inferences or interpretations. In contrast, if a student repeated information or shared other’s ideas without adding any personal comments, then it was a negative indicator. The critical ratio for this category was 0.76 with a standard deviation of 0.29.

Relatively high value of standard deviation indicated that linking was limited in some discussions whereas it was high in some other discussions (See Table 2). This implied that some topics were more prone to linking knowledge, making inferences and interpretations. Some students linked ideas by adding personal comments and interpretation while some students linked ideas to examples, facts, or outside materials. For example, one student shared an example of how a friend's company gained profit in the bidding system. Linking this specific example to a broad concept, another student added:

> That was a good point made by you on the bidding technique carried in your friend's company to earn more profit. Nowadays this technique is widely used by all the construction industries which is called as "Unbalancing the bid" technique. This technique is profitable only if the contract is carried by billings method or percentage of completion method (G2 W3).

The critical ratio for justification was 0.74 with a standard deviation of 0.26. In this study, the students often provided explanations or justifications immediately after proposing opinions. When justification lacked in a student's post, other group members asked questions probing the reason or evidence. For instance, one student asked a peer, "Can you elaborate your last line regarding how the emphasis varies from project to project? What factors are to be considered?" (G4 W3). The student then responded and justified his/her opinion. This kind of back and forth conversation forced students to think critically. However, in this study, only some of the unjustified statements were identified by peers and even less so by the facilitators or instructor.

The final category was critical evaluation which refers to situations where a student critically assesses or evaluates his/her own or others' ideas or contribution to the topic discussed.

Even though the number of units for positive indicator of this category was relatively high (148 total) the critical ratio was relatively low (0.54) compared to other categories. This indicator was often identified when the students accepted or rejected others' opinions with reasonable explanations. For example:

> I see your point but I would say it can't be the case every time. Sometimes a project may not even need the advanced technologies to make it sustainable and it may pass the CHPS standards by using the simple green design measures only. (G3 W3)

Discussion

Results of this study indicated small group format enabled students more equally contribute to discussions and increased the group cohesion. It also encouraged group participants to go above and beyond the minimum requirements and keep the discussion flow through several follow-up posts. This confirmed previous findings that small groups tend to have a higher group density value and are much easier to maintain the interaction [21].

The content of the posts is as important as the nature of peer interaction if not more. Results of this study implied that student-led online discussions encouraged critical thinking in five dimensions: novelty, outside knowledge, linking, justification and critical evaluation. In terms of novelty, content analysis of the posts indicated that students brought in new knowledge, built upon each other's ideas when responding to specific discussion questions. New questions often led to new discussion directions, which expanded or deepen the discussion. However, questions sometimes were directed to a specific participant, which might have excluded input from other students. It would benefit more students if good questions can be identified and highlighted by the facilitator during the discussion. A facilitator can suggest a new direction for the discussion through highlighting a question emerged during the discussions to create longer, more in-depth and qualitatively better threads in small group discussions [23].

Outside knowledge was the next category which indicated that online discussions provide opportunities for every single student bring in their own experiences and knowledge to the table and co-construct knowledge. In this particular course, students with little industry experience had the chance to learn from their peers. In addition to working experiences, grouping students with different academic background, previous knowledge or personal experiences together may also afford more knowledge and experience sharing. Thus, instructors are encouraged to assign students with diverse background into one group to maximize the potential benefits of sharing knowledge and experience to promote critical thinking.

Linking new knowledge to previously learned concepts, making inferences and interpretation is an essential component of critical thinking as it requires students to make connections amongst different sources of information and create their own understanding. Discussion leaders—instructor or student leaders— play an important role in creating opportunities for practicing this skill. Initial post questions and follow-up questions should lead participants to pull information from different sources.

The fourth category was justification which indicated that, as critical thinkers, discussion participants provided justification for their opinions. When justification was missing, peers asked for clarification which forced students to explain the reasoning behind their arguments. Discussion leaders should be proactive in identifying such arguments and ask questions to probe reason and evidence. Asking questions to probe reason and evidence is one type of Socratic questioning. Many studies reported that asking or/and modeling Socratic questions encourage critical thinking [10], [14], [17], [23].

The final category was critical evaluation of which critical ratio was relatively low.

However, the content analysis indicated that negative indicator or critical evaluation was not necessarily a bad thing. Rather, it showed appreciation of peers' contribution [23], which would help to create a friendly and welcoming discussion environment. Facilitators are encouraged to give such comments to show appreciation during the discussion.

Conclusion

The purpose of this study was to investigate the patterns of interaction and level of critical thinking during student-facilitated online discussions in a graduate level civil engineering course. Findings of the social networking analysis in this study indicated small group discussions created opportunities for a high network density that group members were connected to each other. The results of the content analysis indicated that students were engaged in five types of critical thinking in online discussions, and the critical ratio for each category was positive which indicated that students used critical thinking more frequently than they did lower-level thinking.

Pedagogical implications

Based on the findings, following recommendations can be made:

Purposefully form small groups. Students are more likely to draw on personal experiences and bring outside materials into discussions when group members have diverse background as they can bring in different perspectives, experiences, and knowledge, which facilitates knowledge construction and critical thinking. Instructors should form discussion groups to ensure the important student assets are uniformly distributed across groups, and the number of people in each group should be small enough to encourage cohesion.

Include critical thinking indicators in grading rubric. Students' frequent use of outside knowledge category of critical thinking was likely to be related to the grading rubric. Students were clearly communicating about the expectations about reference and support in the rubric which asked to "use references to literature, readings, or personal experience to support comments." By contrast, mixed level of performance in other critical thinking categories might result from the lack of clear requirement and expectations. Describing critical thinking behaviors explicitly in the rubric can be an effective approach to teach students how critical thinking occurs and how they are expected to critically think during the discussions.

Teach facilitation techniques. The findings indicated that the students would have more opportunities to critically think if a facilitator can ask good starting questions (e.g. open-ended questions), encourage follow-up conversations, highlight great topics during the discussion, identify unjustified statements, and ask probing questions [10], [19], [23]. Students usually lack the professional facilitation techniques that instructors can gain from teaching experiences. Therefore, instructors are recommended to provide guidelines that teach facilitation techniques and how to ask good questions.

Limitations and directions for future research

As with any research, this study has some limitations that need to be taken into consideration while interpreting the results. One concern is the possible data interpretation bias due to a single data interpreter. In order to address this concern, the data interpreter received a professional training in qualitative data coding in advance and also had another researcher to review the coding results. The content and structure of online discussions may vary with different engineering programs, which might be further investigated. Although the authors believe that the insights from this study are also applicable to various contexts, educators are encouraged to validate the results in their domains. Finally, a representative sample of discussion forums were selected for analysis in this study. Discussions during a continuous period of time can be analyzed in future to show the evolution of students' use of critical thinking.

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