
EXPLORING THE RELATIONSHIP BETWEEN INTERACTION AND THE STRUCTURE OF QUESTIONS IN ONLINE DISCUSSIONS USING LEARNING ANALYTICS

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Abstract

While research has established the importance of questions as a key strategy used to facilitate student interaction in online discussions, there is a need to explore how the structure of questions influence students' interactions. Using learning analytics, we explored the relationship between student-student interaction and the structure of initial questions with and without the Practical Inquiry Model (PIM). Degree centrality was used as the method to analyse the number of responses each student sent (out-degree centrality) and the number of responses each student received (in-degree centrality). Findings showed that the number of responses each student sent and received was higher in the discussions initiated by the PIM-question prompts. In addition, analysis revealed a positive relationship between students' interaction and the discussions structured with PIM and non-PIM questions. Finally, there was a significant difference in out-degree centrality but no significant difference in in-degree centrality between discussions structured with the PIM and non-PIM questions. We conclude that initial questions can be structured using PIM as a guiding framework to facilitate student-student interaction in online discussions.

Abstract in Russian

В связи с тем, что данные различных исследований доказали важность использования вопросов как ключевую стратегию для интерактивности студентов в онлайн дискуссиях, есть необходимость исследовать как различные типы вопросов оказывают влияние на интерактивность студентов. Использование аналитических данных является одним из эффективных подходов для сбора данных по интерактивности студентов как показателя их взаимодействия друг с другом во время дискуссий. Данное исследование использовало обучающую аналитику для анализа связей между типами вопросов (PIM и не-PIM) и интерактивностью студентов в онлайн дискуссиях. Мы использовали степень центральности как метод анализа количества ответов каждый студент отправил (вне степени центральности) и количества ответов каждый студент получил (в степени центральности). Результаты исследования выявили, что количество ответов каждый студент получил и отправил были выше в дискуссиях, где были использованы типы вопросов PIM. Также результаты показали, что существует положительная связь между типами вопросов и интерактивностью студентов, доказывая что чем больше студенты отвечали, тем больше ответов они получали. Однако, результаты сравнения обеих дискуссий разные. Выявлена значительная разница между интерактивностью студентов и типами вопросов в первой дискуссии, но нет разницы во второй дискуссии в обоих типах вопросов (PIM и не-PIM).

Abstract in Urdu

اگرچہ تحقیق نے سوالات کی اہمیت کو ایک اہم حکمت عملی کے طور پر قائم کیا ہے جو آن لائن گفتگو میں طالب علموں کی بات چیت کو آسان بنانے کے لئے استعمال ہوتا ہے، لیکن اس بات کی بھی ضرورت ہے کہ سوالوں کی ساخت طلباء کی بات چیت کو کس طرح متاثر کرتی ہے۔ سیکھنے کے تجزیات کا استعمال کرتے ہوئے، ہم نے طلباء کی باہمی تعامل اور ابتدائی سوالات کے ڈھانچے کے درمیان کے ساتھ اور بغیر اس کی تلاش کی۔ ڈگری مرکزیت کا استعمال اس طریقہ کے طور پر کیا گیا تھا کہ (PIM) عملی انکوائری ماڈل پر طالب علم کو بھیجے گئے ردعمل کی تعداد (اؤٹ ڈگری مرکزیت) اور ہر طالب علم کو موصول ہونے والے ردعمل کی تعداد (ان ڈگری سوالات PIM مرکزیت) کا تجزیہ کیا گیا تھا۔ نتائج سے معلوم ہوا کہ ہر طالب علم کو بھیجے اور موصول ہونے والے جوابات کی تعداد PIM اور غیر PIM کے اشاروں سے شروع کی گئی مباحثوں میں زیادہ ہے۔ اس کے علاوہ، تجزیہ سے طلباء کی باہمی تعامل اور سوالات کے ساتھ تشکیل دینے والے مباحث کے مابین ایک مثبت تعلقات کا انکشاف ہوا۔ آخر میں، اؤٹ ڈگری مرکزیت میں ایک سوالات کے ساتھ تشکیل دینے گئے مباحث کے مابین ڈگری مرکزیت میں کوئی خاص فرق PIM اور غیر PIM خاص فرق تھا لیکن کو ایک رہنما اصول کے طور پر استعمال کیا جاسکتا ہے جو آن PIM نہیں تھا۔ ہم یہ نتیجہ اخذ کرتے ہیں کہ ابتدائی سوالات کا اہتمام لائن گفتگو میں طلباء کی بات چیت میں آسانی پیدا کر سکتا ہے۔

Keywords: interaction; asynchronous online discussions; question prompts; learning analytics; degree centrality

Introduction

According to the 2017 New Media Consortium Horizon Report, more leaders across the globe emphasize student active learning to advance cultures of innovation. Interaction, as an essential part of student active learning, has become an important component to promote meaningful learning in online courses (Becker et al., 2017). To support student active learning, studies have demonstrated the effectiveness of asynchronous online discussions (Lim, Jeong, Hall, & Freed, 2017; Salter & Conneely, 2015; Xie, Yu, & Bradshaw, 2014). The use of asynchronous online discussions has also demonstrated that students who are usually quiet in traditional classroom discussion become more active and frequently post/respond to others online (Cheng, Paré, Collimore, & Joordens, 2011). However, simply giving students the opportunity to participate in online discussions does not automatically lead to desired student-student interactions. Asking the right type of question can help promote desired student-student online interactions (Ertmer & Koehler, 2014; Richardson & Ice, 2010; Sadaf & Olesova, 2017). Moreover, pre-structured questions based on the use of the framework can help instructors promote desired student-student interactions in asynchronous online discussions (Darabi et al., 2013). However, studies are not consistent in their findings whether pre-structured questions can help promote desired student-student interactions. Some studies (Ertmer et al., 2011; Darabi et al., 2013) found that pre-structured questions can facilitate group interactions. However, other studies (Darabi et al., 2011; Park, 2009) did not find any evidence that pre-structured questions are effective in influencing students' interactions.

This study examined two types of initial discussion questions, (a) questions structured with the four phases of the Practical Inquiry Model (PIM) and (b) questions structured with Andrew's playground type of question. Question prompts that were structured with the PIM included four phases inquiry process:

1. Triggering phase when students become aware of a problem through initiating the inquiry process;
2. Exploration phase when students explore a problem by searching for relevant information and offering explanation;
3. Integration phase when students interpret and construct possible problem solution; and
4. Resolution phase when students defend potential problem solutions with a new idea (Garrison, Anderson, & Archer, 2001).

The PIM framework was selected for this study as the four phases of the model can guide students' interactions from initial inquiry process (triggering and exploration) up to the final application phases (integration and resolution). It was our understanding that being social constructivist in nature, Garrison et al.'s (2001) Practical Inquiry Model (PIM) with pre-structured phases had potential to influence student-student interactions through four phases of the inquiry process. Non-PIM question prompts in this study followed Andrews (1980) typology of questions. Out of nine types of questions suggested by Andrews (1980), a playground type was selected for this study. Similarly, to the PIM questions, playground questions also require the analysis and application of a specific concept, or "playground" for discussion but they are not designed with the four phases of the inquiry process. Although the PIM and non-PIM questions were similar in nature because they both help facilitate student-student interaction, the way they were worded and structured was different. Comparing these two types of questions can provide more insight into how helpful PIM framework with pre-structured phases of the inquiry process can be for creating question prompts to facilitate student-student interaction in online discussions.

To examine student-student interactions, this study used evidence-based learning analytics through student log data on how many responses each student received and sent to others in asynchronous online discussions (Kim, Park, Yoon, & Jo, 2016; Kim, Yoon, Jo, & Branch, 2018; Romero, Lopez, Luna, & Ventura, 2013). Studies have confirmed that evidence-based learning analytics can provide theoretical and empirical evidence of strong relationships between students' log data and student learning (Kim et al., 2016; Zhang, Zhang, Zou, & Huang, 2018). To predict students' successful learning in online discussions, studies have suggested using degree centrality method (Kim et al., 2016; Romero et al., 2013). Degree centrality method includes: (a) in-degree centrality (IDC), the number of replies each student received from others in asynchronous online discussions and (b) out-degree centrality (ODC), the number of replies each student wrote to others in asynchronous online discussions (Kim et al., 2016).

This study is an attempt to shed the light on the relationships between student-student interaction and initial question prompts structured with the PIM's four phases of the inquiry process and non-PIM questions to examine how evidence-based learning analytics can be helpful in understanding the nature of interactions in asynchronous online discussions.

Interaction and Structure of Discussion Questions

Interaction as an essential part of student learning experience in asynchronous online courses is the key for student's success in course completion and learning (Lustria, 2007; Moore, 1989). Although online interactions can occur in a number of different ways, Moore (1989) identified three main types of interactions: student-instructor, student-student, and student-content. Moore (1989) defined student-student interaction as a two-way communication in which one student interacts with other students, alone or working in groups. By interacting with others, students can get feedback from each other, and increase achievement (Anderson, 2003; Moore, 1989). Based on the results of a meta-analysis on the three types of interaction, Bernard et al. (2009) concluded that incorporating interaction and, specifically, student-student interactions within distance education courses had a positive impact on student learning. In another meta-analysis, Borokhovski, Tamim, Bernard, Abrami, and Sokolovskaya (2012) also found that student-student interactions had positive effect on student achievement. Other studies also found that student-student interaction a strong predictor of student satisfaction, effective learning and success in asynchronous online courses (Huss, Sela, & Eastep, 2015; Kuo, Walker, Belland, & Schroder, 2013; Sher, 2009). Overall, studies are consistent in their findings that student-student interaction has a positive impact on learning outcomes but there is still a need to explore what treatments students need to interact more with each other.

It is known that asking thoughtful questions play an important role to provide more opportunities for students to interact with each other (Bernard et al., 2009; Ertmer, Sadaf, & Ertmer, 2011). Several studies have examined question prompts as an effective instructional strategy to increase student-student interaction in asynchronous online discussions (Brooks & Jeong, 2006; Darabi et al., 2011; Ertmer et al., 2011; Gilbert & Dabbagh, 2005). For example, Darabi et al. (2011) examined a series of question prompts to facilitate group interaction and to advance students through the phases of pre-structured question prompts. They found that even though pre-structured question prompts were intended to engage students, students were still not consciously engaged in interaction with each other compared with debate or role-play online discussions. However, in another study, the authors found that students who used pre-structured question prompts generated more messages stimulating more subsequent student responses in asynchronous online discussions (Darabi et al., 2013). Similarly, Kim et al. (2016) also found that pre-structured questions could initiate a dialogue and generate more interaction among students in online discussions. Ertmer et al. (2011) also examined pre-structured question prompts and found that student responses to the questions that require comprehension, synthesis, and application of the content averaged the highest number of posts per student. While these studies suggest that pre-structured questions can generate more student-student interaction, they do not provide much insight into the relationship between the types of questions and student-student interaction in asynchronous online discussions.

Interaction and Learning Analytics

Learning analytics, as a new and growing field proved to be an effective approach in investigating students' interaction in asynchronous online discussions (Avella, Kebritchi, Nunn, & Kanai, 2016; Ifenthaler, 2017). Learning analytics is an emerging discipline "concerned with developing methods for exploring the unique types of data that come from educational settings and using those methods to better understand students, and the settings which they learn in" (Berland, Baker, & Blikstein, 2014; p.209). In other words, learning analytics is the process of collecting and analysing electronic data about learners and their learning to offer instructors and instructional designers' opportunities to improve a course design, development, and implementation which result in student success (Hernández-García & Suárez-Navas, 2017). Moreover, learning analytics can provide theoretical and empirical evidence of strong correlation between students' log data and actual learning (Kim et al., 2016). Students' log data are used in learning analytics to provide information about students' online learning behaviours including their interactions in asynchronous online discussions. For example, log data provide information on the number of posts each student made in asynchronous online discussions or how many replies each student posted during the week.

Using learning analytics in asynchronous discussion forums can help interpret the patterns of online interaction and predict students' success in asynchronous online courses (Avella et al., 2016; Kim et al., 2016; Romero et al., 2013; Sergis & Sampson, 2017). However, the lack of comprehensive view of the information integrated in online discussion forums can prevent course instructors evaluate dynamics of student-student interactions (Hernández-García & Suárez-Navas, 2017). A thorough selection of relevant indicators to track student-student interactions has become another important element of evidence-based learning analytics. Studies have widely discussed the types of indicators and how many indicators are relevant to use to analyse student-student interactions (Hernández-García & Suárez-Navas, 2017; Tempelaar, Rienties, Mittelmeier, & Nguyen, 2018; Xing, Guo, Petakovic, & Goggins, 2015). For example, Romero et al. (2013) found that using wrong indicators could result in drawing the wrong conclusions.

As interaction is a social element, studies have discussed indicators that include members of the network to analyse student-student connections in asynchronous online discussions (Romero et al., 2013). Studies proposed degree centrality as a strong indicator of student-student interactions to predict reciprocal interactions between individuals (Hernández-García & Suárez-Navas, 2017). Kim et al. (2016) examined student success factors in asynchronous online discussions and found that out-degree centrality (ODC) or the number of responses each student sent was one of the strongest indicators of students' success in online courses.

Research purpose and questions

Questions are a key strategy used to facilitate student interaction in online discussions, thus it is important to understand how different types of questions influence students' subsequent responses and interactions. The purpose of this study was to determine the relationship between the type of initial question prompts (PIM and non-PIM) and student-student interaction in online discussions using degree centrality as the method of analysis. The following research questions guided this study:

- What is the impact of the structure of question prompts (PIM and Non-PIM) on student-student interaction in online discussions?
- What is the relationship between student-student interactions and the structure of question prompts (PIM and non-PIM) in online discussions?
- What is the difference between the structure of question prompts (PIM and non-PIM) and student-student interaction in online discussions?

Method

This study used a non-experimental quantitative research design with the use of students' log data to examine their interaction dynamics through degree centrality as a strong indicator of relationship between student-student interactions and the structure of question prompts.

Participants

A purposeful sample (Patton, 1990) of forty-five graduate students (20 males and 25 females) enrolled in an Educational Technology course at a Mid-Western university participated in this study. The sample was included in the study because students were randomly enrolled in two sections of the same online graduate course and participated in the same online discussions. The two sections were designed and taught by the same course instructor. Although the discussions were graded as part of the course, students were informed that they had the right to opt-out by not signing a consent for being included in the study. All students agreed to participate in the study and signed the online Instructional Review Board (IRB) consent form.

The independent variables of the study were two question prompt structures: (a) question prompts structured with the four phases of the Practical Inquiry Model (PIM questions) and (b) question prompts structured with Andrew's playground type of question (non-PIM questions). The dependent variable was the student-student interactions. Students ($n = 25$) in section one received question prompts structured with the four phases of the Practical Inquiry Model (the PIM-section) while students ($n = 20$) in section two received question prompts structured with Andrew's playground type of questions (non-PIM section). The students ranged in age from twenty-one to forty-five years. Most ($n = 37$) of the participants had taken three or more online courses prior to participating in this study.

Context of the study

This study used the online course “Foundations of Educational Technology” offered over a sixteen-week semester and delivered via a learning management system, Blackboard. Students were required to participate in a weeklong asynchronous online discussion as part of their course grade. During the semester, there were ten discussions on various topics on educational technology. For this research, we selected and analysed four case-based discussions in week three and four – two from each section with same cases on the same topics “Learning Theories” in week three and “Constructivist Learning Theory” in week four. Students compared and discussed advantages and disadvantages of the alternative solutions of the problems in each case. Both cases described a scenario in which a specific learning theory/theories and instructional principles were applied to solve the issue. Students were required to explore and analyse the case situations in order to propose and justify possible solutions to the issues presented in the weekly case (see Figure 1).

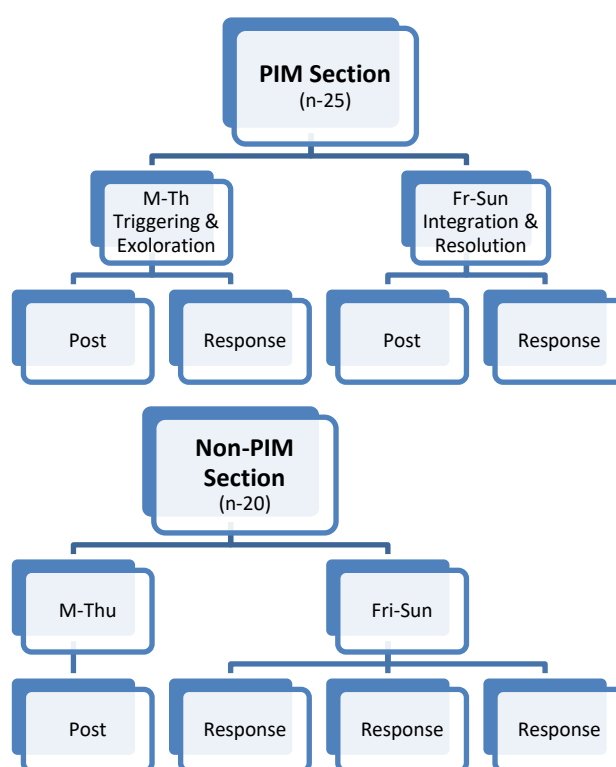


Figure 1. The structure of online discussions in PIM and non-PIM sections

Students in the PIM-section received a case followed by question prompts representing four levels of the model, i.e., triggering, exploration, integration, and resolution under two different threads. Students were required to respond to “triggering” and “exploration” questions the first half of the week (Monday to Thursday) within the first thread and comment on one other student post. The purpose of asking triggering and exploration questions during the first half of the week was to first help students understand the nature of the problem and then explore relevant information to provide possible explanations. During the second half of the week, students were required to respond to “integration” and “resolution” questions within the second thread during second half of the week (Friday to Sunday) and comment on one other student post. The purpose of asking questions at integration and resolution phases was to help students build on their initial discussion responses to create solutions of the problem and provide justifications for their solutions of the problem. In total, students were required to make at least four posts for one week – two initial posts and two comments on others.

Example for Triggering and Exploration Phases: What do you think are the problems with the way Mr. Cantrell has designed his instruction [*Triggering question prompt*]? How can your [use the one you have been assigned] theoretical perspective help to understand the problems presented in this case [*Exploration question prompt*]?

Example for Integration and Resolution Phases: Briefly identify a key principle (or principles) taken from the theoretical perspective and explain how it would be applied to solve the learning problem presented in the case [*integration question prompt*]. Justify your response by providing applications of your solutions in real world situations [*resolution question prompt*].

Students in the non-PIM section were presented with the same cases as students in the PIM-section but the structure of their question prompts were based on the Andrews (1980) playground question within a single thread. Playground question type was selected because it represents a traditional discussion method of posting a response to one discussion prompt within one single thread and then replying to three other students. In this study, the playground question prompts referred to a specific concept in the course and required students to analyse and apply that concept. Students interpreted the specific information (i.e., learning theories) and used that information to solve the issues presented within the cases studies. Students in this section were required to respond in one post during the first half of the week (Monday to Thursday) and then comment on three other students' posts during the second half of the week (Friday to Sunday). In total, students were required to make at least four posts for one week – one initial post and three comments on others.

Example of the Andrew's Playground Question Type: From your theory's [*use the one you have been assigned*] viewpoint of learning, identify the learning problems in Mr. Cantrell's class. How can your theoretical perspective help to understand the problems presented in this case? Briefly identify a key principle (or principles) taken from the theoretical perspective and explain how Mr. Cantrell can design instruction applying the principle (or principles) to solve the learning problem in his class.

Although the PIM and non-PIM questions both tend to facilitate student-student interaction and application-level responses, the way they were worded and structured were different. For example, PIM followed Garrison et al.'s (2001) practical inquiry model to create the question prompts and required student initial responses in two separate threads. On the other hand, non-PIM discussion questions followed Andrews (1980) playground questions to create the question prompts and required students to post their initial response in a single thread. Comparing these two types of question structures may provide more insight into how useful PIM framework is for wording and structuring initial question prompts to facilitating student-student interaction in online discussions.

Data Collection and Analysis

In order to quantify student interactions, we used degree centrality as an indicator of student-student interaction in asynchronous online discussions (see Figure 2). Kim et al. (2016) validated the accuracy of degree centrality as a proxy variable of the prediction model. Overall accuracy reached over 70% which means that over 70% of the students could be predicted as low and high achievers at early stage of the course. In-degree centrality (IDC) when students received responses and out-degree centrality (ODC) when students sent responses were analysed by counting the connections each student had established with their peers (Dawson, Macfadyen, Lockyer, & Mazzochi-Jones, 2011). Following Kim et al. (2016) research, IDC was calculated as total number of replies received by students and divided by the number of students minus one (n-1) and ODC was calculated as total number of replies students sent to others divided by the number of students minus one (n-1).

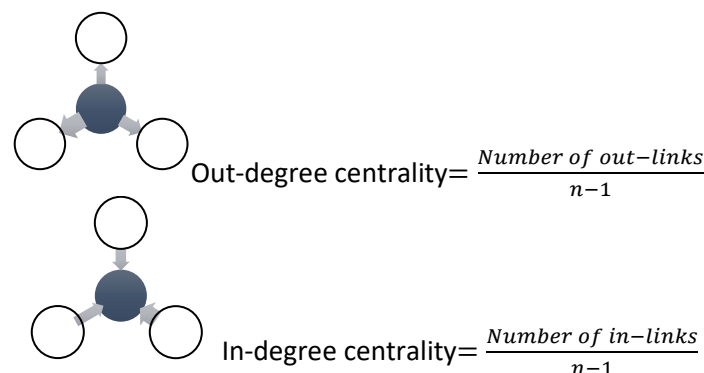


Figure 2. Calculating degree centrality

Quantitative data were collected from four online discussions– two from the PIM-section and two from the non-PIM section of the same online graduate course including students’ responses to/from others ($n = 733$). In the PIM-section where students received the question prompts structured with the four levels of Practical Inquiry Model, we collected 496 students’ postings including 184 postings they received from others and 312 postings they sent to their peers. In the non-PIM section where students received question prompts structured with the Andrew’s playground question, we collected 237 student postings including 113 postings students received from others and 124 postings they sent to their peers (see Table 1).

Table 1: Average number of posts per student response in the PIM and non-PIM sections

	PIM Section (n = 25)			Non-PIM Section (n = 20)		
	In-degree Centrality	Out-degree Centrality	Total	In-degree Centrality	Out-degree Centrality	Total
Number of posts	184	312	496	113	124	237
Average posts per student	7.36	12.48	19.84	5.65	6.2	11.85

Descriptive statistic was used to calculate total number of replies received by students per question and divided by the number of students to explore the extent to which a student in the social network contributes to online discussions. A Pearson correlation analysis was applied to determine the relationship between in-degree centrality and out-degree centrality for discussions structured with PIM and non-PIM prompts. Additionally, independent *t*-test was conducted to examine differences between the PIM and the non-PIM sections for student-student interaction (IDC and ODC).

Results

Impact of the Structure of Question on Student-Student Interaction

To answer the first research question, descriptive statistics was run. The results revealed that ODC or the number of responses each student sent to other students was higher for the PIM questions in both discussions (Table 2). However, the PIM questions had higher IDC or the number of responses each student received from others in the first discussion while the non-PIM questions had higher IDC in the second discussion. Higher ODC implies active students who eagerly responded to others students. Higher IDC implies a higher degree of prominence of the actor (replies) in the network (Kim et al., 2016).

Table 2: Distribution of in-degree and out-degree centrality across two discussions and groups

	PIM Group (n = 25)		Non-PIM Group (n = 20)	
	Discussion #1	Discussion #2	Discussion #1	Discussion #2
In-Degree Centrality	0.21	0.11	0.12	0.14
Out-Degree Centrality	0.30	0.24	0.18	0.20

Relationship between Student-Student Interaction and the Structure of Question Prompts

To answer the second research question, Pearson correlation analysis was applied to determine the relationship between student-student interactions (ODC and IDC) and the structure of question prompts (PIM and non-PIM). The analysis revealed there was a medium positive correlation between IDC and ODC in the PIM-structure ($r = .37, n = 25, p > .05$) with 13.69 shared variance. This means that the number of responses each student received (IDC) can explain about 14% of the variance the number of responses each student sent (ODC). Further, there was a large positive correlation between IDC and ODC in the non-PIM section ($r = .68, n = 20, p < .05$) with 46.24 shared variance. This means that the number of responses (IDC) each student received can explain almost 46% of the variance for the number of responses each student sent (ODC) in the non-PIM structure.

Differences between Student-Student Interactions and the Structure of Question Prompts

To examine differences in out-degree centrality and in-degree centrality between the PIM and the non-PIM sections, an independent t -test was conducted. Results revealed a significant difference in out-degree centrality between PIM ($M = 0.54, SD = 0.22$) and non-PIM prompts ($M = 0.37, SD = 0.16$); $t(43) = 2.94, p < .05$ with large effect size eta squared 0.17. The differences between two sections across two online discussions were also examined by running independent t -test. The test revealed significant differences for ODC between two sections in the first online discussion (PIM: $M = 0.30, SD = 0.12$) and (non-PIM: $M = 0.18, SD = 0.07$); $t(43) = 4.24, p < .001$ with large effect size eta squared 0.29. However, there were no significant differences for ODC in the second online discussion between both sections.

To examine differences in IDC between the PIM and the non-PIM sections, independent t -test revealed there was no significant difference in in-degree centrality between PIM ($M = 0.31, SD = 0.20$) and the non-PIM ($M = 0.26, SD = 0.14$) sections revealed no significant difference (PIM: $M = 0.31, SD = 0.20$) and (non-PIM: $M = 0.26, SD = 0.14$); $t(43) = 1.18, p < .05$ with small effect size eta squared 0.03. The test revealed differences for IDC in the first online discussion between two sections (PIM: $M = 0.21, SD = 0.14$) and (non-PIM: $M = 0.12, SD = 0.08$); $t(43) = 2.32, p < .05$ with moderate effect size eta squared 0.11. There were no significant differences for IDC in the second online discussion between both sections.

Discussion

The results revealed that the out-degree centrality or the number of responses each student sent to others was higher during both discussions with PIM questions compared with both discussions with non-PIM questions. These results are consistent with Darabi et al. (2013) who found that pre-structured question prompts generate more messages triggering subsequent responses. This study found empirical evidence that questions structured with four levels of cognitive presence can lead to more interaction when students are asked to collaboratively solve a case. This may be due to the nature of the questions that were designed to facilitate sustained reflection and discourse in a critical

community of inquiry (Garrison et al., 2001). In this study, the discussions with PIM questions required students to first discuss the triggering and exploration questions in the first thread where students were presented with a triggering question and then they begin to understand the problem through engaging in a meaningful dialogue. Later, student discussed the integration and resolution questions in the second thread where students built on each other's ideas and synthesized information to provide real-world solutions. These findings emphasize the importance of structuring initial discussion questions that require students to interact with their peers to collaboratively construct knowledge beginning with recognizing the problem and progressing to solving the problem (Richardson, Sadaf, & Ertmer, 2012; Sadaf & Olesova, 2017).

The results provide empirical evidence that there was a medium positive correlation between in-degree centrality and out-degree centrality for PIM-section and strong positive correlation for non-PIM section. This suggests that when students send more responses to others, they receive more responses from others. This relationship between student-student interaction of giving and receiving replies is more likely to happen during discussions designed with the non-PIM questions. For discussions with non-PIM questions, students participated in the conventional method of responding to one discussion prompt within one single post and then replying to three other students. Requiring students to post responses on three other posts may have resulted in creating a strong relationship between sending and receiving replies. While the PIM-questions helped students move through several phases of meaningful discourse towards in-depth discussion, this structure resulted in creating medium relations between in-degree centrality and out-degree centrality. For PIM questions, students were required to make one post and respond to one student during first half of the week and then make second post and respond to one student during the second half of the week. One possible reason may be that students had less time to become familiar with the PIM discussion prompts and were more focused on responding to the questions rather than creating back and forth conversations. Darabi et al. (2011) noted that presenting a series of questions under different threads made discussion more complex than the conventional method of just responding to one discussion prompt.

Additional results indicate that there was a significant difference in out-degree centrality between PIM and non-PIM sections; however, this study did not find significant difference in in-degree centrality or the number of responses each student received from others between two sections. These results imply that students tend to send more replies to their peers in response to the previous postings in discussions designed with four levels of the PIM – from triggering events up to resolution level where students justified or defended their solutions of the problems. This is consistent with previous reports of a positive relationship between structured questions and student replies (Darabi et al., 2013; Sadaf & Olesova, 2017). Hosler and Arend (2012) noted that when instructors ask questions that require integration of ideas and solving problems, students tend to critically examine the problems by exchanging viewpoints, exploring applications to problems, and synthesizing ideas to provide solutions. Replying to others' posts require students to reflect on others' messages and therefore establish a mutual communication among students towards in-depth discussions (Dawson, 2008). It was clear that student-student interaction in discussions with the PIM questions was high. Guided by the questions designed with the levels of cognitive presence within PIM, students actively interacted with their peers to collaboratively move beyond their initial understanding of the case and critically analysed the problems as well as created and justified their solutions. These activities require social learning that builds on reciprocal interaction between students and the knowledge is constructed by the interactions of individuals within collaborative learning environment (Hernández-García & Suárez-Navas, 2017).

For in-degree centrality, students received more responses from their peers in the first discussion structured with the PIM questions and in the second discussion structured with non-PIM questions. These results showed that student-student interaction in terms of IDC was not consistent in both discussions structured with PIM and non-PIM questions. In addition, there were significant differences in the first online discussion between both sections while the second online discussion did not reveal any significant differences. This implies that the questions structured with PIM or non-PIM may or may not impact student-student interaction in terms of the number of responses students receive from other students. Although students' postings received replies from other students and triggered subsequent postings in the first discussion facilitated by the PIM questions, it did not happen in the second discussion. This may be due to the difference in how the PIM questions were worded. Sadaf and Olesova (2017) concluded in their study that the nature of the case and the wording of the questions can be influential in student learning. A closer look at how the questions were worded may provide a better picture of why IDC was higher during one discussion and not the other.

Although high in-degree centrality is important in showing higher degree of prominence of an actor in the network, out-degree centrality is more important for student-student interaction when students intentionally reply to other students' posts. Kim et al. (2016) stated that "in-degree centrality does not necessarily imply student productivity even though it represents the student's prominence within a network structure" (p.39). This suggests that when students respond to PIM questions, their posts may or may not receive attention and trigger subsequent replies. Therefore, this cannot be interpreted as an effort of the student to interact with other students to construct knowledge.

Conclusion and Implications

Online discussions structured with PIM questions can have more student-student interaction than discussions with non-PIM questions in terms of ODC or the number of responses students sent to other students. On the other hand, student-student interaction in terms of IDC was not consistent in both discussions facilitated by PIM and non-PIM questions. One of the practical implications of this study is to structure online discussions in one thread per week. Having discussions in two different threads dividing two different discussions during one week can decrease student-student interactions. Discussion in one thread during the week can give students more time to develop stronger relationship in terms of both ODC and IDC. For example, students can spend one week discussing the triggering/exploration questions and another week to discuss integration and resolution questions. Another implication is that online instructors can construct question prompts using all four phases of the PIM to create favourable conditions for frequent student-student interactions. However, discussion questions should be carefully worded and topics for discussion should be carefully selected to facilitate more student-student interactions.

Although previous research suggests a positive relationship between discussions structured with PIM questions and student replies (Darabi et al., 2013; Sadaf & Olesova, 2017), this study showed a medium positive relationship between out-degree and in-degree centrality for PIM questions in online discussions. In this regard, instructors can intervene in discussion drawing students' attention to other students' viewpoints and ask students to provide reflections on other students' responses. Instructors' help in moving discussions through the stages of cognitive presence – triggering, exploration, integration, and resolution – may lead to more interaction as each stage offers a process that encourages knowledge construction through deep levels of discourse among students that happens through student-student interactions. In online discussions, posting and replying are important for articulating ideas to argue, support, clarify, and provide evidence (Shukor, Tasir, Van der Meijden, & Harun, 2014). Course instructors can ask additional questions

prompting students to integrate their ideas with those presented by someone with a different view and respond to their posts. This can establish student-student interaction with a shared communication network among students towards more reflective discussions.

This study examined the relationship between the structure of initial question prompts designed with and without Practical Inquiry Model (PIM) on student-student interaction using evidence-based learning analytics. Considering the results of the study, it can be concluded that evidence-based learning analytics such as in-degree centrality and out-degree centrality can help course instructors track data to increase student-student interactions using the structure of questions prompts. This study also concluded that correctly selected indicators of student-student interaction can help course instructors understand how students interact in online discussions in threaded discussions. Overall, the findings in this study are valuable because they contribute to further effective design of online discussions across different disciplines.

Limitations and Future Research

When interpreting our results, it is important to recognize the limitations of our study. First, this study is limited in generalizability of findings due to small sample size and participants representing a convenient sample from only one program and university. Follow-up studies could utilize large sample size with data collected across programs or institutions to further refine the results and implications of this study. In addition, having only two discussions with PIM questions and two discussion with non-PIM questions limited examination of student-student interaction, especially for degree centrality. Future research can be conducted to compare the relationships between students' interaction and their learning outcomes; whether students who interact more actively may achieve higher learning outcomes such as grades, level of cognitive presence, and cognitive engagement.

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