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A network-based analytic approach to uncovering the relationship between social and cognitive presences in communities of inquiry

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ABSTRACT

This paper presents a network-based approach to uncovering the relationship between the elements of social and cognitive presences in a community of inquiry. The paper demonstrates how epistemic network analysis (ENA) can provide new qualitative and quantitative insights into the students' development of social and critical thinking skills in communities of inquiry. More specifically, ENA was used to accomplish three different research goals: i) uncovering links between social and cognitive presences of communities of inquiry; ii) evaluating the effectiveness of two instructional interventions on student experience as measured by connections between cognitive and social presences; and iii) exploring how the relationship between social and cognitive presences changed over time during a course. The proposed approach was applied to the coded transcripts of asynchronous online discussions performed in a fully-online graduate level course. The results of this study showed that indicators of social presence had more association with the exploration and integration phases of cognitive presence. Besides, indicators of the affective category of social presence had stronger links with the two high levels of cognitive presence (i.e., integration and resolution), while indicators of interactive messages of social presence were more connected to the two low levels (triggering events and exploration) of cognitive presence.

1. Introduction

Asynchronous online discussions are fundamental to facilitate social interaction within fully online and blended courses in higher education (Anderson & Dron, 2010). They play an essential role in educational experience of students encouraging them to increase their course participation by answering questions, sharing resources, and solving problems, for instance (Hew & Cheung, 2008). Researchers have shown several benefits of online interactions (critical thinking, creativity, and argumentation) rising the need to better understand how asynchronous online discussions can be used to promote learning and knowledge (co-)construction in a group of students (Garrison, Cleveland-Innes, & Fung, 2010; Dawson, Tan, & McWilliam, 2011).

The social constructivist model called Community of Inquiry (CoI) is a well-known framework that aims to outline how asynchronous online communication shapes student learning and their cognitive development (Garrison, Anderson, & Archer, 1999). The CoI model defines three dimensions that mold the learning experience (i.e., social presence, cognitive presence, and teaching presence) and assumes an overlapping relationship among the three presences that enhance the students on-line learning capability (Kozan & Richardson, 2014). Over the years, many studies have shown the practical value and benefits of the CoI model, such as the influence on the engagement of students and learning outcomes (Garrison, Anderson, & Archer, 2010), applications in computer-supported collaborative scenarios (Joksimović, Gašević, Kovanović, Adesope, & Hatala, 2014), and the relationships between use of educational technology by the learners and the dimensions of the CoI model (Kovanović, Gašević, Joksimović, Hatala, & Adesope, 2015).

This paper proposes the adoption of a network analytic approach to advance insights into the relationship between social and cognitive presences in asynchronous online discussions. Unlike most of studies that focused on this relation with self-report instruments, the current study uses coded transcripts of asynchronous online discussions. The methodological contribution of this study is the use of Epistemic Network Analysis (ENA) (Shaffer et al., 2009) to study the association between the social and cognitive presences. ENA allowed for better understanding of the association between the four phases of cognitive presence and the indicators of social presence. The proposed network analytic approach was further applied to assess the effects of an intervention aimed to foster higher levels of cognitive presence in a fully-

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online graduate-level course in software engineering over six offerings. Finally, the way how the relationship between social and cognitive presences changes over time was also investigated with ENA. The study presented here has practical implications both in terms of the use of the proposed network-based analysis and the results of the application of the methodology of analysis.

2. Theoretical background

2.1. The community of inquiry model

According to (Garrison, Anderson, & Archer, 2010), the Community of Inquiry (CoI) model is the most widely-used and researched theoretical framework that outlines the important facets of social interactions in online and blended education. CoI explains behaviors of students and instructors with the purpose of describing how educational experience can be more effective by providing three indicators of their relationships, known as presences (Garrison et al., 1999):

- **Social presence** measures the ability to humanize the relationships among participants in a discussion. A higher number of posts, in general, indicates the improvement of social presence.
- **Cognitive presence** is highly related to the concept of knowledge construction and problem-solving. It aims to explain whether the meaning making and progress of the interactions in the students' cognitive process supports the development of critical thinking.
- **Teaching presence** concerns instructors and students' role before (i.e., course design) and during (i.e., facilitation and direct instruction) the course. (Anderson, Rourke, Garrison, & Archer, 2001).

The studies that examined the relationship among the three CoI presences revealed that the integrated analysis of the three dimensions could possibly provide useful insights about learners and social knowledge construction processes (Garrison & Cleveland-Innes, 2005; Kozan, 2016; Kozan & Richardson, 2014). The existing studies have predominately used self-reported data, mainly based on the CoI questionnaire (Arbaugh et al., 2008), to investigate the relationship among presences.

Table 1 shows the main categories of the presences. As the main purpose of the study reported in this paper was to analyze the relationship between social and cognitive presences, the rest of this section detail these two presences further.

Garrison and Arbaugh (2007) define social presence as an ability of self-projecting and establishing personal and purposeful relationships. In contrast to a face-to-face interaction, in online discussions, it is essential to textually express such abilities in order to establish a socio-emotional communication. As listed in Table 1, the social presence includes three categories:

i) **Affective** is associated with emotion, feelings and mood expressions. This category aims to examine the translation of real emotions into text. The expression of emotions, the use of sense of humor, and self-disclosure are indicators in this category.

ii) **Interactive** focuses on the exchange of messages; It aims to enhance open communication among participants. Besides social interaction, compliments, expressions of appreciation, and mutual awareness also have a strong value in this category. The indicators in this category include continuing a thread, quoting messages or explicitly referring to messages from the others, asking questions, complimenting expressing appreciation, expressing agreement.

iii) **Group cohesion** seeks to uncover the sense of union and group commitment. The messages in this category normally refer to a third person. The indicators in this category include vocatives and addressing or referring to the group using inclusive pronouns.

Table 1
CoI presences and their respective categories (Garrison & Arbaugh, 2007).

Presence	Categories
Cognitive	Triggering event Exploration Integration Resolution
Social	Affective expression (affective) Open communication (interactive) Group cohesion
Teaching	Design & organization Facilitating discourse Direct instruction

Table 2 presents each indicator divided by social presence. Social presence has a crucial role in the CoI model by providing indicators for measuring sociability, personal relations, and interaction. However, social presence is not sufficient to offer a complete assessment of educational experience (Garrison & Cleveland-Innes, 2005). Thus, Garrison and Arbaugh (2007, p.162) also proposed cognitive presence defined as "*a cycle of practical inquiry in which participants move deliberately from understanding the problem or issue through to exploration, integration, and application.*" This cycle is embraced by the categories shown in Table 1:

i) **Triggering event** is the phase that initiates the cycle of critical inquiry, a problem or dilemma commonly proposed by the instructor or a question asked by a student.

ii) **Exploration** includes an exploration of ideas and reflection, participants are invited to explore the nature of the problem. It involves brainstorming and the exchange of the findings.

iii) **Integration** is the phase in which students connect relevant information and findings and formulate hypotheses. This phase is characterized by the construction of the meaning from the ideas and the information collected.

iv) **Resolution** is the phase in which students evaluate newly-constructed knowledge through hypothesis testing or vicarious application to the problem/dilemma that triggered the learning cycle.

The four phases of cognitive presence are theorized as being differentiated across two orthogonal dimensions: 1) *perception–awareness* dimension, which captures the differences between early and late stages of cognitive presence, and 2) *deliberation–action* dimension, which differentiates between phases that primarily occur in the shared world of the student discourse (triggering event and resolution) and the ones that happen in the private world of reflection (exploration and integration).

Although social and cognitive presences unveil valuable insights into interactions of students individually, their relationship is also important. Thus, the next subsection reviews existing studies that investigated associations between social and cognitive presences.

2.2. The relationship between social and cognitive presences

Research of the relationship among the three presences received considerable attention since the initial proposal of the CoI model (Garrison et al., 1999). However, until 2007 research related to CoI focused on the analysis of the individual presences alone. This changed after Garrison and Arbaugh (2007) claimed that the efforts should be dedicated to the framework as a whole and not only to individual presences. They proposed that it is important to gain more practical insights into the interconnections of the presences. This led to an increase in the number of studies on these interconnections, and the research community addressed several research questions regarding the association between the social and cognitive presence, such as "Can the combination of social and

Table 2
Indicators social presence (Rourke, Anderson, Garrison, & Archer, 1999).

Category	Indicator	Description	Label
	Expression of emotions	Conventional expressions of emotion, or unconventional expressions of emotions, includes repetitious punctuation, conspicuous capitalization, emoticons.	Emotions
Affective	Use of humor	Teasing, cajoling, irony, understatements, sarcasm.	Humor
	Self-disclosure	Presents details of life outside of class, or expresses vulnerability.	Self_disclosure
	Continuing a thread	Using reply feature of software, rather than starting a new thread.	Continuing_Thread
	Quoting from others' messages	Using software features to quote others entire message or cutting and pasting selections of others' messages.	Quoting_Message
	Referring explicitly to others' message	Direct references to contents of others' posts.	Referring_Message
Interactive	Asking questions	Students ask questions of other students or the moderator.	Asking_Question
	Complimenting, expressing appreciation	Complimenting others or contents of others' messages.	Complimenting
	Expressing agreement	Expressing agreement with others or content of others' messages.	Agreement
	Vocatives	Addressing or referring to participants by name.	Vocatives
Cohesive	Addresses of refers to the group using inclusive pronouns	Addresses the group as we, us, our, group.	Group
	Phatics, salutations	Communication that serves a purely social function greeting, closures.	Salutations

cognitive presence predict learning outcomes?" (Garrison & Cleveland-Innes, 2005); "Can social presence detract from cognitive presence?" (Garrison & Arbaugh, 2007); and "Is it possible to reach the higher levels of cognitive presence by improving the social presence?" (Garrison, Anderson, & Archer, 2010). In general, there are two approaches to answering such and other questions concerning the relationship between the social and cognitive presences:

- Methods based on a questionnaire, in which the students are asked to complete a survey about their perceptions during the course;
- Methods based on content analysis of online discussions, in which experts manually annotate discussion transcripts extracted from the online discussions based on the three presences of CoI.

Several questionnaires have been used to analyze the perception of students about their experience within a CoI (Díaz, Swan, Ice, & Kupczynski, 2010; Swan et al., 2008; Yen & Tu, 2008). The most widely used is the instrument proposed by Arbaugh et al. (2008), in which a 34-item survey measures the perception of the students regarding the three presences using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Although there is still some work needed on refining the CoI instrument, the current form is reliable and provides support for the validity of the CoI framework (Garrison, Anderson, & Archer, 2010).

Kozan and Richardson (2014) have used the CoI instrument to investigate the relationship of the three CoI presences over six different undergraduate level courses (Arbaugh et al., 2008). The students completed the questionnaire at the end of the courses as part of the evaluation procedure. The analysis showed a strong positive correlation between social and cognitive presences. This correlation indicates that the higher levels of social presence are positively related to the higher levels of cognitive presence. Moreover, the correlation coefficient revealed some 44% shared variance between the cognitive and social presences. Kozan and Richardson (2014) also showed that teaching presence might have had a limited effect on the relationship between the cognitive and social presences. In a follow-up paper, not only did Kozan (2016) evaluate the correlation among the two presences, but also among some specific indicators. Their results confirmed the Kozan and Richardson (2014) findings, and also provided some new insights. For example, the correlation of the group cohesion (social presence) and triggering event (cognitive presence) was 0.662 (Kozan, 2016). Following a method similar to that applied by Kozan (2016), Gutiérrez-Santiuste, Rodrguez-Sabiote, and Gallego-Arrufat (2015) confirmed the associations between the three presences. The only difference is that Gutiérrez-Santiuste et al. (2015) applied the questionnaire proposed by (Díaz et al., 2010) to receive responses from 65 undergrad students in a blended learning environment. The analysis showed a strong correlation between the social and cognitive presences. Besides that, Gutiérrez-Santiuste et al. (2015) presented a correlation analysis measured through different online resources like chat, forum, and email.

The results above have also been replicated in a Korean context with the (Arbaugh et al., 2008) survey instrument translated in the Korean language (Mo & Lee, 2017; Yu & Richardson, 2015). The Korean study was with first-year students who were enrolled in a liberal arts program (Yu & Richardson, 2015). Once again, the authors found a strong correlation between social and cognitive presences.

Fewer studies have followed the second approach, i.e., content analysis of transcripts of online discussions, to assess such a relationship (Lee, 2014; Morueta, López, Gómez, & Harris, 2016). In content analysis, at least two expert coders manually classify messages from online discussions according to the indicators of the CoI presences of interest. Lee (2014) analyzed messages of several online discussions extracted from two courses performed by graduate students in the Department of English Education at a Korean University. The courses used online discussions to promote higher-order thinking skills of the students in a blended learning environment, and the instructor kept interventions to a minimum in both courses. Their findings showed that social presence had a positive correlation to cognitive presence. In such a case, more interactions under different social presence indicators such as expressing emotions, self-disclosure, and asking questions led to higher levels of the cognitive presence.

The study conducted by (Morueta et al., 2016) explored the social and cognitive presences of students solving complex cognitive tasks in online discussion forums. Specifically, the study analyzed the performance of the students enrolled in a course 'Intervention on risk behaviors' across three different tasks. Three coders classified the messages generated by the 206 undergraduate students in an online course using the presences of the CoI model. The results showed that the students reached different levels of cognitive and social presences on various tasks; however, all scenarios revealed a positive correlation between social and cognitive presences.

Finally, it is essential to remark that teaching presence is also relevant in the development of both cognitive and social presences. Shea and Bidjerano (2009) concluded that teaching presence can significantly predict cognitive presence, and Garrison and Cleveland-Innes (2005) pointed out that the design of online discussions can improve both cognitive and social presences. Garrison, Cleveland-Innes, and Fung (2010) showed that teaching presence predicts both the social and cognitive presences and that social presence mediates the relationship between teaching and social presences.

3. Research questions

Section 2.2 stressed the importance of analyzing the relationship between social and cognitive presences. As presented, several studies have addressed this relationship, in general, using correlation analysis between self-reported measures. However, there has been much less research on that association with the use of content analysis. Moreover, the existing research offers little insight into how phases and indicators of cognitive and social presences are related to each other. Thus, the first research question in the current study was:

RESEARCH QUESTION 1. *What are the association between the individual phases of cognitive presence and the indicators of social presence?*

Besides that, this current study aimed to investigate the extent to which associations between the components of social and cognitive presences were affected by the scaffolding interventions as manifestations of teaching presence. Specifically, this paper examines the scaffolding approach proposed by Gašević, Adesope, Joksimovic, and Kovanovic (2015) that is based on externally-facilitated regulated learning and student role assignments. While Gašević et al. (2015) provide general evidence of the effectiveness of the role-assignment scaffolding; it is relevant to examine how interventions affected the development of cognitive presence in relation to the development of social presence. As such, the second research question was formulated as:

RESEARCH QUESTION 2. *What are the effects of the instructional scaffolds aimed at promoting cognitive presence on the association between the phases of cognitive presence and indicators of the social presence?*

Finally, not only was the present studied interested in the analysis all the data aggregated after the end of the course, but it also aimed to better understand how the relationships between social and cognitive presences evolved, as proposed by (Akyol & Garrison, 2008; Vaughan & Garrison, 2006). Such an analysis is fundamental because the indicators could be extracted in real-time to inform the instructor to support the students to reach higher levels of social and cognitive presences. Such points led to the formulation of the final third research question:

RESEARCH QUESTION 3. *How do the associations between the phases of cognitive presence and the indicators of social presence evolve over time, under the use of the different instructional scaffolds?*

That is, the third research question sought to investigate the evolution of the associations between social and cognitive presences under the scaffolding conditions studied in the second research question.

4. Method

4.1. The data and course design

The data used in the present study consisted of six offerings (Winter 2008, Fall 2008, Summer 2009, Fall 2009, Winter 2010, Winter 2011) of a master level research-intensive course in software engineering offered entirely online, through the Moodle LMS, at a Canadian public university between 2008 and 2011. In those six offerings, a total of 81 students posted 1747 messages. The course encompassed six modules that covered 14 different topics related to software engineering. The students were evaluated by the course instructors on four assignments (TMA1–4):

- **TMA1**: 15% – presentation of a published peer-reviewed paper about one of the topic of the course;
- **TMA2**: 25% – writing a literature review paper on a selected topic in software engineering;
- **TMA3**: 15% – answering six questions (one for each module) to demonstrate critical thinking and synthesis skills;
- **TMA4**: 30% – final project.

As part of the TMA1 assessment, the students were required to select one research paper on a topic in software engineering, record a video presentation, and post a URL to a new course online discussion, in which the other students would engage in the debate around their presentation. In this case, the students that posted the video were considered the **experts** of the discussions, while the rest of the class were the **practicing** researchers in a role-assignment scheme. The participation in such an online discussion accounted for the remaining 15% of the grade (Gašević et al., 2015).

During the first two offerings of the course, the participation of the students was primarily driven by the extrinsic motivational factors (i.e., course grade), with limited scaffolding support. In this study, the students from the first two offerings are referred to as the *control group*, which consisted of 37 students who produced 845 messages. After the first two course offerings, a scaffolding of discussion participation through role assignments and clear instructions were implemented. In total, 44 students, referred to as the *treatment group*, were exposed to such an scaffolding intervention, and produced a total of 902 messages. More details about the intervention are presented in Appendix A.

The dataset was coded according to the indicators of social presence and the phases of cognitive presence. For each message, the coders annotated 1 and 0 for the presence and absence of an indicator of social presence, while the absence of any of the four phases of cognitive presence was coded as "other." Initially, the messages were coded by two expert coders according to the phases of the cognitive presence as suggested by Garrison, Anderson, and Archer (2001). The coders achieved an excellent level of agreement for both presences reaching a (percentage of agreement = 98.1%, Cohen's k = 0.974) with a total of only 32 disagreements which were resolved through discussion. Table 3 shows the number of messages in each cognitive presence for the different roles and groups of students.

A similar process was performed to assess social presence of the students. However, in that case, each message could be coded with more than one indicator as social presence has a high co-occurrence of codes (Richardson, Swan, Lowenthal, & Ice, 2016). Thus, the final number of annotations was 3770, instead of 1747 (the total number of messages). The coders used the scheme defined by Rourke et al. (1999) to code the presence or absence of each social presence indicator, shown in Table 1. The coders achieved a high level of agreement, with

Table 3
Distribution of cognitive presence phases.

ID	Phase	Messages									
		Control				Treatment					
		Expert		Practicing		Expert		Practicing		Total	
	Other	33	8.01%	38	8.78%	29	6.62%	40	8.62%	140	8.01%
	Triggering Event	41	9.95%	155	35.80%	47	10.73%	65	14.01%	308	17.63%
	Exploration	208	50.49%	182	42.03%	130	29.68%	164	35.34%	684	39.15%
	Integration	101	24.51%	51	11.79%	184	42.01%	172	37.07%	508	29.08%
	Resolution	29	7.04%	7	1.62%	48	10.96%	23	4.96%	107	6.12%
	All phases	412	100.00%	433	100.00%	438	100.00%	464	100.00%	1747	100.00%

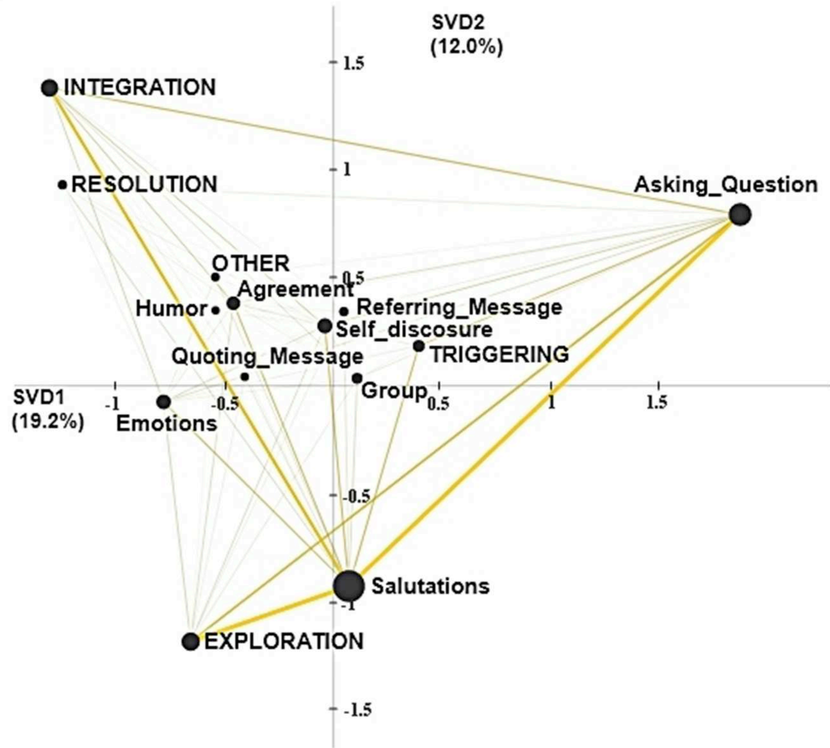

Fig. 1. The relationship between social and cognitive presences for all students group-average networks graph.

all of the indicators reaching a percentage of agreement of at least 84% (Kovanović, Joksimović, Gašević, & Hatala, 2014). Table 2 presents the statistics for coding results of the social presence. It is important to remark that Kovanović et al. (2014) omitted some of the indicators from their analysis (i.e., Continuing a thread, Complementing, and Vocatives) because they had a disproportionately large number of messages with such codes. The present study also excluded the same indicators from the analysis.

In order to improve the readability of the results presented here, a label for each social presence indicator was created as shown in Table 2.

4.2. Epistemic network analysis

The three research questions were answered by using Epistemic Network Analysis (ENA). ENA is a graph-based analysis technique which can be used to examine rich relationships between a set of concepts. In educational settings, ENA is typically used to investigate the associations between codes of a coding scheme (e.g., phases of cognitive presence or indicators of social presence) where the coding scheme is applied to analyze transcripts of online discussions (Cai et al., 2017; Ferreira, Kovanović, Gašević, & Rolim, 2018; Gašević, Joksimović, Eagan, & Shaffer, 2018). Unlike other network analysis techniques, ENA was primarily designed for problems with a relatively small set of concepts characterized by highly dynamic and dense interactions. It can also be used to compare the differences between the different groups of the analysis units.

Within ENA, connections among codes are derived for each unit of analysis (e.g., study subject) based on the code co-occurrences in the data subsets called stanzas (e.g., sentence, paragraph, and document). From code co-occurrences, ENA first creates a high-dimensional representation, called the analytic space, of all analysis units. The units of analysis are then projected onto a lower-representational space, called the projection space, which is derived from the analytic space through the singular-value decomposition (svd). At the end, the output of ENA is a series of graph models which capture the relationships between the different codes (Shaffer, Collier, & Ruis, 2016). Appendix B is introduced to provide an illustrative example of the application of ENA and the additional insights that are necessary for the understanding of ENA.

The current study analyzed two different configurations of networks. The first one employed the student and individual posts as the unit of analysis and stanza, respectively. They were used to answer research questions 1 and 2 formulated above. As research question 1 aimed to better understand the general relationship between social and cognitive presences, we explored the mean network of all students together. Then, to address research question 2, we divided the students into the treatment/control and expert/practicing researcher groups to better understand the differences in the links between social and cognitive presences. To reach such a goal, we explored both the projection and subtraction networks. The projection network was used to extract the projection points (i.e., svd1 and svd2 values) of each participant in the study. The differences between the student groups on both svd1 and svd2 values were then compared by using a series of the Mann-Whitney tests (Ruxton, 2006) with $\alpha = 0.05$. The subtraction network was used to explain the qualitative differences between the student groups.

As research question 3 aimed to analyze the temporal issues in the association between cognitive and social presences, we used a different configuration in the application of ENA. Week and day were adopted as the unit of analysis and stanza, respectively. This analysis produced a different network graph (i.e., the meaning of the svd values were different from those produced by ENA applied to research questions 1–2). The most critical analysis here was with trajectory graphs. It is important to mention that our analysis was performed for the different weeks of the course. Thus, the analysis over time meant a study about how the students changed their associations between the social and cognitive presences from one week to the following one.

5. Results

5.1. Research question 1

Fig. 1 shows the group-average graph for all students with the relationships between social and cognitive presences. The visualization was done using svd_1 and svd_2, which accounted for 19.2 and 12% of variability of the epistemic networks created by the students, respectively. The results obtained indicate that the Y-axis (i.e., svd_2) primarily distinguishes between students focusing more on the early phases (triggering event and exploration) or the later phases (integration and resolution) of cognitive presence. In general, the social presence indicators were represented at the center of the network, except for asking questions, indicating that the sole importance of this asking question indicator in the course, which is primarily captured by the X-axis (i.e., svd_1).

Table 5 presents the strength of each connection from Fig. 1 with the values higher than 0.40 emphasized. There were several strong connections within the social presence indicators, such as the link between Salutation and Asking Questions (2.19). However, focusing on the relationship between the codes of the two presences, one can highlight: i) Salutations and Asking Question had strong connections with all four phases of the cognitive presence, especially with the exploration where the values reached 2.21 and 1.28, respectively; ii) integration had links to Emotions, Agreement, and Self-Disclosure; iii) Besides Salutation, Resolution did not reach links with any other indicator of the social presence with a value higher than 0.40. As expected, there were no connections between the cognitive presence phases because of our analysis that coded entire messages for cognitive presence (i.e., no co-occurrence between the phases of cognitive presence was possible).

5.2. Research question 2

The differences between the students in the different groups (expert–control, expert–treatment, practicing researcher–control, and practicing research–treatment) are shown in Fig. 2. The critical difference between the control and treatment groups was along the X-axis, and a higher variance between the expert and practicing researcher roles was across the Y-axis. The circles represent students in the expert–control (light red), expert–treatment (dark red), practicing researcher–control (light blue), and practicing researcher–treatment (dark blue) groups, while the rectangles represent group-average networks and the rectangles are surrounded with lines representing 95% confidence intervals.

In order to better understand the impact of both instructional interventions (role assignment and externally-facilitated regulated learning) individually, we analyzed each of them separately. Fig. 2 shows the projection graph for role assignments. The Mann-Whitney test revealed a significant difference between experts (red) and practicing researchers (blue) across the X-axis ($U = 6584.50$, $p = 0.001$; $r = 0.91$). The effect size of 0.91 is considered large according to Cohen (1992).

Fig. 3b shows the subtracted graph (i.e., the difference between the two networks) between the experts and practicing researchers. The figure reveals that the expert group had more connections with codes within the Affective and Cohesive indicators of social presence than the practicing researcher groups. The practicing researcher group had a higher number of links to the Interactive indicators of social presence especially to Asking Questions. The experts had more connections with the Integration and Resolution phases of cognitive presence. The practicing researchers tended to publish more messages with links to the categories of Exploration and Triggering Events of cognitive presence.

Similarly, Fig. 4a presents the difference between the control (green) and treatment (purple) groups. The main contrast between the groups was over the Y-Axis ($U = 2165.50$; $p = 0.001$; $r = 0.37$), reaching $r = 0.37$ which implies a small to medium effect size Cohen (1992). It is important to note that the Y-Axis characterized the differences across the phases of the cognitive presence – with integration and resolution having higher values than those of triggering events and evaluation. That is, the students in the treatment group had more links between all other codes and the integration and resolution codes than their peers from the control group.

Fig. 4b presents the subtracted graph of the control (green) and treatment (purple) groups. It indicates far more connections of the indicators of social presence to the integration and resolution phases for the treatment group than in the control group; likewise, there was a higher number of links to the triggering event and exploration phases in

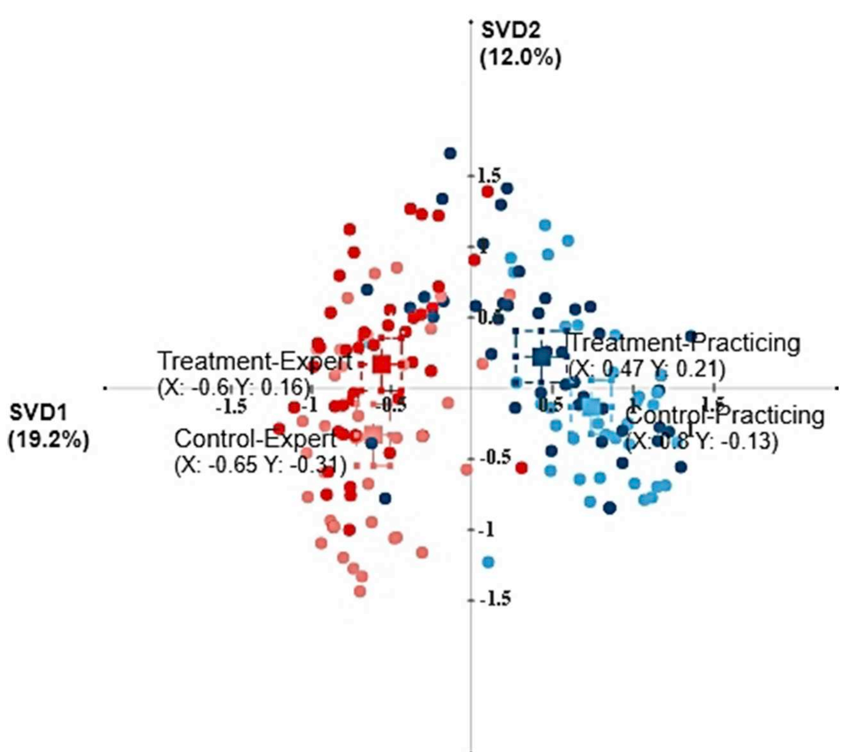

Fig. 2. ENA projection of the networks of the students of social and cognitive presences. The different colored circles represent the different groups: expert–control (light red), expert–treatment (dark red), practicing researcher–control (light blue), and practicing researcher–treatment (dark blue), while their group means are shown as colored squares (95% confidence intervals are outlined around the group means). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

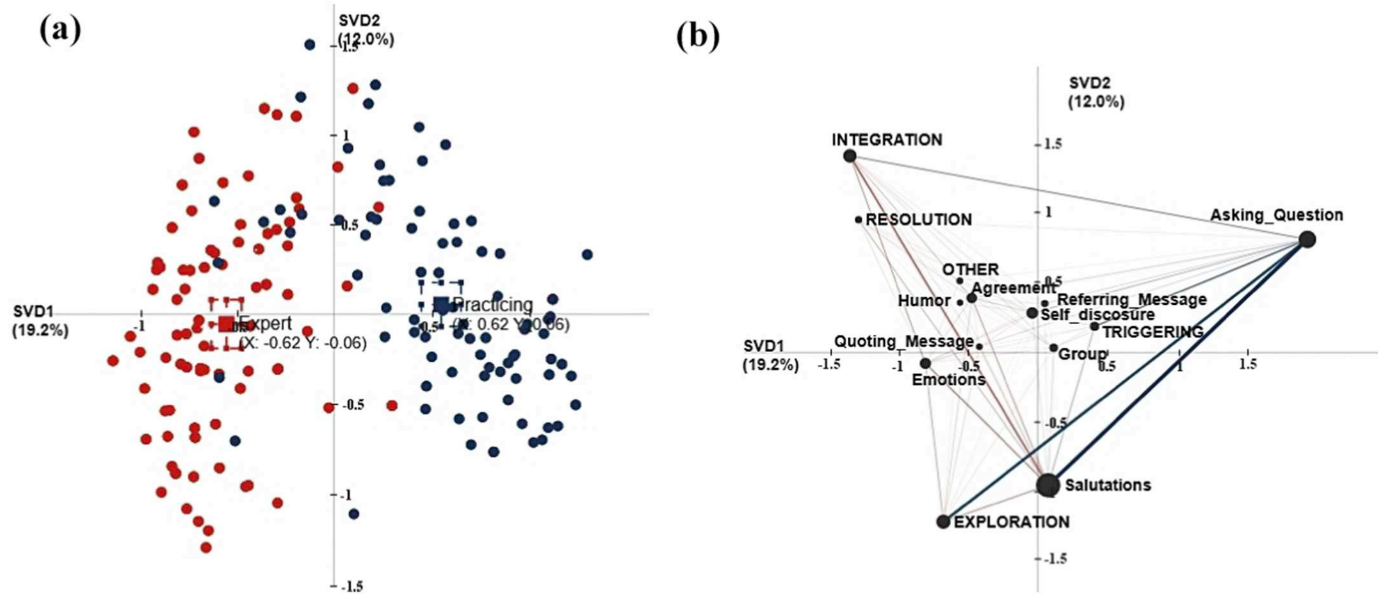

Fig. 3. Comparison between experts (red) and practicing researchers (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the control group than in the treatment group.

5.3. Research question 3

The results of the development of the relationship between the social and cognitive presences developed over time are reported where changes from one week of discussions to another week were analyzed. Initially, we investigated the number of messages in each of the social presence indicators and cognitive presence phases for different weeks. The results are shown in Table 4 and indicate that the weeks in the middle (week 2 and week 3) tended to have more messages across the different categories, and in general the number of posts in week 1 was almost the same as in week 4.

ENA was employed to explore in detail how the two presences were related to each other by creating a new high-dimensional representation using weeks as the unit of analysis and days as stanzas. Fig. 5a shows the final network built using the entire dataset. Again, the visualization was done using svd_1 and svd_2, which accounted for 39.6 and 16.4% of variability, respectively. In contrast to Fig. 1, the network in Fig. 5a is highly connected, including connections between the different phases of cognitive presence. By considering days as stanzas, several messages were encapsulated together in the same analysis, and thus different phases of the cognitive presence could co-occur. Another interesting observation is that the phases of cognitive presence were plotted in distinct parts of the graph, leaving the category *other* in the middle.

The trajectory of the different groups over the four weeks are shown in Fig. 5b, which was plotted in the same high-dimensional space as it was done in Fig. 5a. The trajectory visualization shows the location of the main activity performed by each group of students in each week of

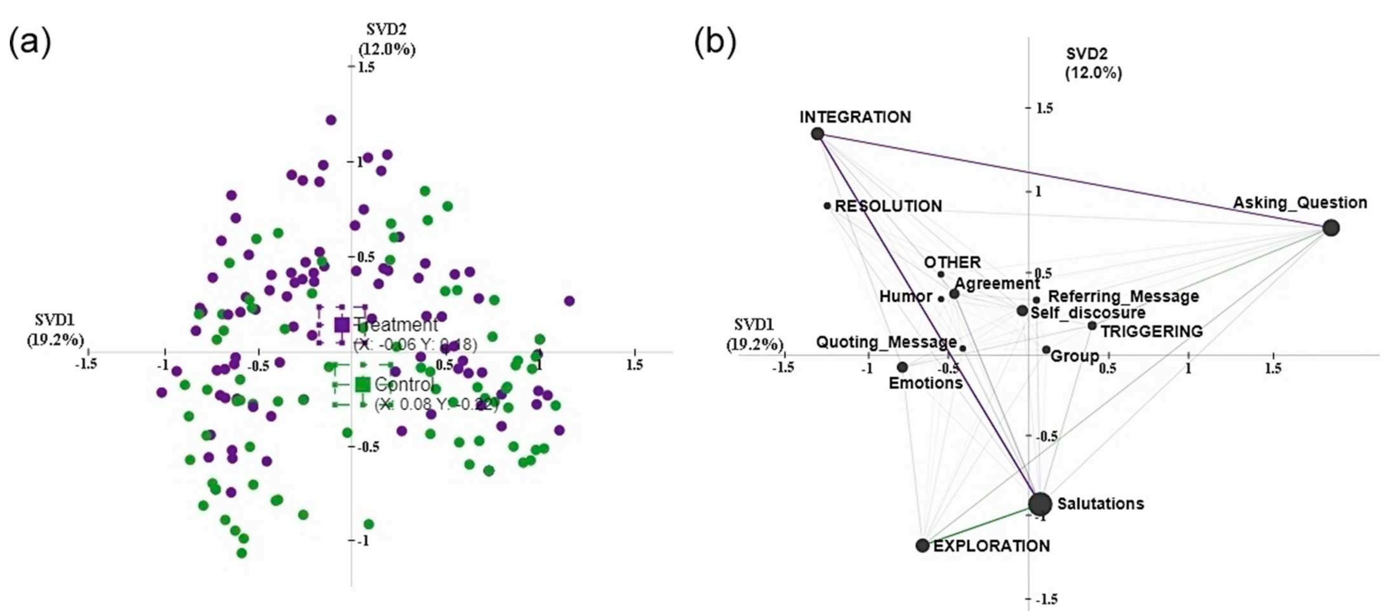

Fig. 4. Comparison between the control (green) and treatment (purple) groupss. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 4
Distribution of social presence phases.

Category	Messages									
	Control				Treatment				Total	
	Expert		Practicing		Expert		Practicing			
Affective	135	32.77%	131	30.25%	152	34.70%	112	24.14%	530	30.34%
Interactive	392	95.15%	433	100.00%	414	94.52%	464	100.00%	1703	97.48%
Group Cohesion	373	90.53%	399	92.15%	364	83.10%	401	86.42%	1537	87.98%
All phases	900	100.00*%	963	100.00*%	930	100.00*%	977	100.00*%	3770	100.00*%

the discussion connected by a line which represents how the groups evolved from one week to the following one. This analysis revealed that the students assigned to the practicing researcher role in the control group (blue) finished the discussion (week4) almost in the same place where they had started in week 1; all the other groups moved towards the left-upper side, where the *resolution* was placed. That is, the other three groups (experts in both the control and treatment groups and practicing experts in the treatment group) demonstrated a steady progress by making fewer links to the phases from the lower levels of cognitive presence and by increasing the links with the higher levels of the cognitive presence as the weeks in the course were passing by.

6. Discussion

6.1. Research question 1

The results of the current study unveiled that the codes representing indicators of social presence were distributed over the X-Axis, Fig. 1. Interactive indicators were located more on the right-hand side of the graph, especially the Asking_Question indicator. The Cohesive indicators were in the middle and the Affective on the left-hand side. This can be explained by the fact that the Interactive category of social presence is generally associated with the Triggering Event phase of cognitive presence, while the Affective category of social presence is related to higher levels of cognitive phase (Morueta et al., 2016).

Fig. 1 also shows that the Y-axis primarily differentiates between the low (triggering event and exploration) and the high (integration and resolution) phases of cognitive presence. This is fully aligned with the conceptualization of cognitive presence (Garrison et al., 2001). Specifically, the Y-axis primarily differentiates across the deliberation-action dimension of the practical inquiry model with the higher levels of cognitive presence in the upper part of the diagram.

Moreover, Fig. 1 makes important and novel insights into the relationship between social and cognitive presences explicit. As already mentioned, the connection between Triggering event (cognitive presence) with Asking_Question (social presence) was expected since Triggering event is a phase of cognitive presence in which the process of problem recognition usually starts through asking questions. Table 5 shows that Asking_Question also had strong connections to Exploration and Integration. This probably happened since the dataset used in the study was coded using the entire message as the unit of analysis, which can contain traces of more than one phase of the cognitive presence. Thus, the coders were asked to choose the traces of the highest phase of the cognitive presence phase by following the code-up rule proposed by Garrison et al. (2001). A further study using a sentence or a paragraph as the unit of analysis, instead of the entire message, could reveal complementary knowledge about the relationships between social and cognitive presences (Aviv, Erlich, Ravid, & Geva, 2003; Rourke et al., 1999). For instance, the relationship between Asking_Question and Integration reveals that messages in the Integration phase not only could finalize the development of an idea, but they could also raise new, deeper, and content related questions (Schrire, 2006). The example is an Integration message that includes a question.

"Hi, great presentation well done. A quick comment and question. I agree with you that the paper would have been better if they split the theory and implementation in two different papers. Nonetheless in their implementation was there any benchmarking on the time/performance of the transformations? The results gave 306 tuples produced with no

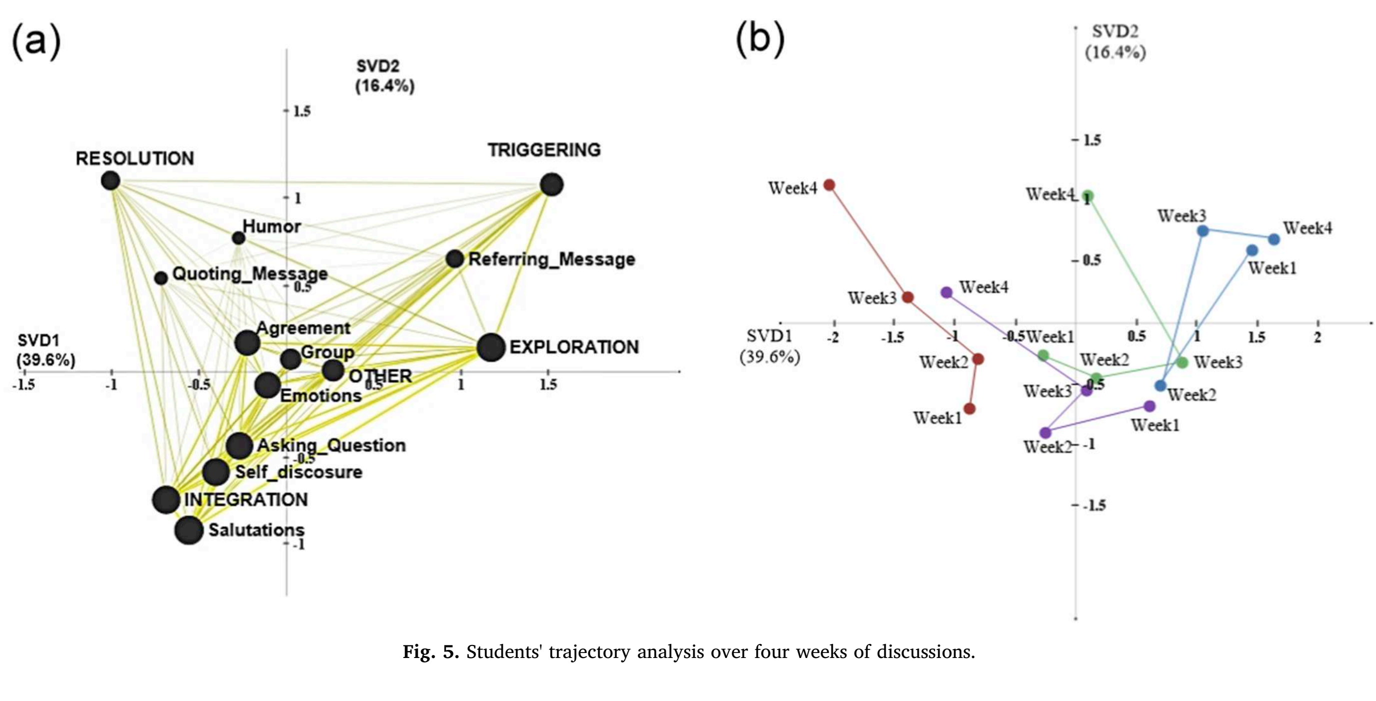

Fig. 5. Students' trajectory analysis over four weeks of discussions.

Table 5
Symmetric matrix presenting the relationship between social and cognitive presences ENA network weights.

	TRIG	EXPLO	INTEG	RESO	OTHER	Humor	Emotions	Agreement	Quot_Mess	Group	Self_disc	Salutations	Reff_Mess	Ask_Ques
TRIG	0.00	0.00	0.00	0.00	0.00	0.02	0.16	0.03	0.02	0.11	0.16	**0.89**	0.03	**0.86**
EXPLO	–	0.00	0.00	0.00	0.00	0.04	**0.44**	0.37	0.13	0.20	0.37	**2.21**	0.16	**1.28**
INTEG	–	–	0.00	0.00	0.00	0.07	**0.46**	**0.59**	0.11	0.30	**0.59**	**1.68**	0.15	**0.89**
RESO	–	–	–	0.00	0.00	0.03	0.11	0.13	0.03	0.03	0.15	**0.40**	0.05	0.18
OTHER	–	–	–	–	0.00	0.03	0.20	0.06	0.02	0.05	0.14	0.30	0.00	0.08
Humor	–	–	–	–	–	0.00	0.10	0.04	0.00	0.03	0.09	0.11	0.01	0.07
Emotions	–	–	–	–	–	–	0.00	0.22	0.08	0.16	0.39	**0.84**	0.08	0.30
Agreement	–	–	–	–	–	–	–	0.00	0.04	0.14	0.21	**0.78**	0.08	**0.40**
Quot_Mess	–	–	–	–	–	–	–	–	0.00	0.00	0.05	0.25	0.01	0.02
Group	–	–	–	–	–	–	–	–	–	0.00	0.14	0.39	0.03	0.24
Self_disc	–	–	–	–	–	–	–	–	–	–	0.00	**0.88**	0.06	**0.54**
Salutations	–	–	–	–	–	–	–	–	–	–	–	0.00	0.29	**2.19**
Reff_Mess	–	–	–	–	–	–	–	–	–	–	–	–	0.00	0.18
Ask_Ques	–	–	–	–	–	–	–	–	–	–	–	–	–	0.00

restrictions. The UML models the authors used as their example were very simple and small. On a model of any significant size the Cartesian product for the weaving would be very large (assuming no restrictions). With restrictions, the tuples were reduced to 12 which was much better but still, we're dealing with a simple model. Perhaps speed was not really a concern but I was thinking how this transformation capability could be useful in a real-time/changing environment. Cheers!"

The study results also demonstrated that all indicators of the Affective category of social presence had weak links with Triggering event. This can be explained by the fact that at the beginning of the discussion (Triggering event) the students, in general, did not share affective messages. Besides that, the strong connections between Salutation and all the phases of cognitive presence are indicative of the students' efforts to establish social presence. Regarding the exploration phase, one can observe an extensive increase of the weights of the links with all indicators of social presence; this increase could mean the creation of a group cohesion identity, because the students were more open to sharing their thoughts about the content using different expressions of social interactions (Kozan & Richardson, 2014; Morueta et al., 2016).

The two highest phases of cognitive presence had some interesting connections. The Integration phase had the highest weights for connections with all the affective indicators of social presence, and with Group and Salutation, as shown in Table 5. This could indicate that the students improved the social "climate" of the online discussion forum, because of the increase in the affective relationships and group cohesion (Gunawardena, 1995). On the other hand, the Resolution phase shows a decrease in the weights of the links with all the indicators of the social presence. One can speculate that such a decrease is due to the fact that in the Resolution phase the students were exhibiting their final findings and solutions, reducing their interaction.

6.2. Research question 2

Research question 2 aimed to examine the effects of the two instructional interventions reported in the (Gašević et al., 2015) study, as briefly explained in Section 4.1. The results presented here revealed the effect the two instructional intervention had on both social and cognitive presences, Fig. 2. The two interventions were analyzed separately in order to better understand the impact of each one of them.

The analysis of role assignment (Fig. 3a) showed the large effect sizes for svd- svd_1 (X-axis), suggesting significant differences, in particular relating to the different indicators of social presences. It should also be noted that the move from the role of practicing researcher to the role of expert resulted in (a) social presence shifting from interactive to affective indicators and (b) cognitive presence leaning towards higher levels. This result makes sense as the expert role was designed to be in charge of driving the discussions. Such a leadership role encompassed the aid given to the other students to reach the final cognitive phases and the group cohesion, corroborating what the literature says that the demands of group cohesion to have more sense of humor to reduce the social distance (Rourke et al., 1999). Moreover, the integration phase of cognitive presence promotes the convergence and connection of the ideas among the group members. Similar findings were also shown using the subtracted network model (Fig. 3b), albeit in a more condensed form where it was evident that the students assigned to the role of practicing researchers had stronger connections between Triggering event and Exploration messages to the social presence indicators, while the experts made more links with the codes representing the Integration and Resolution phases of cognitive presence and the indicators of social presence.

Regarding the effect of externally-facilitated regulated learning intervention on the phases of cognitive presence (i.e., control and treatment groups), Fig. 4a shows that the main difference between the groups was across the Y-Axis. That is, the students in the treatment group were plotted closer to the higher levels of cognitive presence than the ones in the control group. This corroborates the findings of the previous studies that used statistical and network methods to analyze the effects of such an intervention (Gašević et al., 2015).

The subtracted network model (Fig. 4b) confirmed that the shift in the behavior of the students after the intervention was more related to the cognitive presence phases. A relevant finding uncovered from this figure is that although the indicator Asking_Question was relevant for all students, the students in the treatment group posted more critical and more profound messages, while the students in the control group mostly started discussions and explored preliminary ideas.

6.3. Research question 3

The last research question proposed an analysis of how the relationship between social and cognitive presences evolved over time. Initially, we analyzed this relationship by showing descriptive statistics of the number of messages in each category per week (Table 6). The results obtained revealed similar findings as those reported in the

Table 6
Number of posts by social category and cognitive phases per week.

		Week1	Week2	Week3	Week4
Social	Affective	105	175	161	89
	Interactive	307	536	540	320
	Group cohesion	285	468	489	295
Cognitive	Other	30	45	39	26
	Triggering Events	79	96	99	34
	Exploration	119	197	219	149
	Integration	74	186	160	88
	Resolution	21	30	33	23

previous studies pointing out that the number of messages increased in the three initial weeks and then decreased in the last week (Week4) (Akyol & Garrison, 2008; Vaughan & Garrison, 2006). The results also unveiled the relationship between the indicators of the Affective category of social presence and the Integration phase of cognitive presence. As well, the results showed links of the indicators from the Interactive and Group Cohesion categories of social presence with the Resolution phase of cognitive presence. However, a further in-depth analysis is needed to test if these links still hold in other different samples that were collected in courses a) across different subject areas; b) that followed different instructional designs; and c) that had larger student enrollments.

After the initial analysis, the trajectory analysis provided by ENA was performed. The final graph (Fig. 5b) presents an insightful overview of how the participation of each group of the students changed over the four weeks of the online discussion. Taking into account only the control group, the graph showed a completely different behavior, especially considering the variance explained by the X-Axis (39.60%). The practicing researchers in the control group finished the last week almost at the same point where they had initially started their cognitive presence in week 1; that is, they primarily posted messages related to Triggering event and exploration. In contrast, experts in the control group focused on posting integration and resolution messages. This shows the extent of the effort need from the students in charge of the discussion (expert) in the control group to create an environment in which they can advance their critical thinking, problem-solving, and knowledge (co-)construction skills by reaching higher levels of cognitive presence. It is important to remark that in this case the X-Axis essentially differentiates across the deliberation-action dimension of the practical inquiry model that underlies the conceptualization of cognitive presence (Fig. 5a). Thus, the experts in the control group seemed to have been trying to help the other students to go from theory (triggering event and exploration) to the creation of new concepts and their practical application (integration and resolution).

Both groups of students (experts and practicing researchers) in the treatment group, in general, had similar trajectories in the links between social and cognitive presences. Their trajectories started close to each other, and both of them converged to the resolution phase. This supports the effectiveness of the instructional intervention designed to support the development of cognitive presence, as reported by Gašević et al. (2015). The main difference is at the beginning of the trajectory when the experts started (week 1) closer to the triggering event and exploration phases, and then moved onto the integration (week 2) phase, and finally converged to the resolution phase (weeks 3–4). On the other hand, the practicing researchers started the discussion by being close to the integration phase (week 1 and week 2), then moved back closer to the triggering event and exploration phases (week 3) before converging to the resolution phase (week 4).

This analysis showed that the trajectory networks have a strong potential to pinpoint several new practical applications of the community of inquiry model. They could be a powerful tool to aid the instructors to improve the educational experience of the students in online discussions by giving timely feedback and support them in the development of the teaching presence (Anderson et al., 2001).

6.4. Limitations of this study

There are some limitations of the present study which should be acknowledged. First, the data is from a single course at a single institution, although from six-course offerings. This can negatively affect the degree of potential generalization of the analysis and the results of the method presented. Second, it is possible that the findings from the present study are somewhat limited, given the specificity of the adopted course design, instructional intervention and the duration of the discussions in the course (four weeks) combined with the position of the discussions early in the course (weeks 2–5) (Akyol & Garrison, 2008). Finally, the method applied in data coding and analysis required many methodological decisions, such as deciding on how the unit of analysis and the coding used for cognitive and social presences. It might be the case if the coding process were performed by adopting different coding schemes (for example, the ones proposed by Richardson et al. (2015); Richardson, Maeda, Lv, and Caskurlu (2017)) or on a different set of data would lead to different findings.

7. Conclusions and lines for further work

The primary contribution of the present study is a novel network analytic method for the assessment of the relationship between social and cognitive presences. Through a graph-based analysis, called Epistemic Network Analysis, in-depth insights into the connections among the social presence indicators and the cognitive presence phases were uncovered. Moreover, by examining these two presences at the student level instead of at the message level, a much richer understanding of the development of the students was gained, going beyond simple message counts and statistical correlations. Additionally, the analysis of the student development of cognitive and social presences over time provided insights into how their behavior changed in each week of the course. In practical terms, the presented data analysis method can be reproduced in different course designs and scenarios aiming to enable instructors to provide a better facilitation of the course participation of the students by offering timely feedback concerning both presences. Moreover, the proposed method can be helpful in the improvement of course designs before future offerings, primarily because ENA can provide not only quantitative but also qualitative insights into the students' interactions. For example, this new information could be used to reshape the syllabus, by giving more emphasis on the critical topics, and providing awareness about the scaffolding interventions proposed.

Another substantial contribution of the present study is the investigation of the outcomes of the instructional scaffolding through externally-facilitated regulation and role assignment to support the development of social and cognitive presences. While the general benefits of this instructional scaffolding in the same dataset were already explored by Gašević et al. (2015), the current study showed how the intervention affected the relationship between social and cognitive presences and how their relationship developed over the four weeks of the course. This analysis has the potential to provide relevant research evidence not only on the benefits of the different instructional interventions but also to inform the development of next-generation tools in learning analytics and early warning systems that are focused on the mixed qualitative and quantitative analysis and support of asynchronous online discussions.

Finally, this work can be extended and improved in several ways. In the short-term future, the authors intend to: i) investigate how social presence interacts with the course topics (similarly to the work of Ferreira et al. (2018) that looked at the associations between the course topics and the cognitive presence); ii) use an approach similar to the one presented in this study to analyze the relationship of teaching presence with both social and cognitive presences; and iii) apply the same methodology to assess different coding schemes for cognitive and social presences, the datasets from other courses topics, following different designs, and in different languages. In the long-term, the network analytic approach presented in this paper can be used as a basis for the development of a platform that can help instructors and students to reach an enhanced educational experience in asynchronous online discussions following the CoI model. This is particularly promising considering the recent progress in the use of machine learning methods to automate the coding process of online discussions with the phases of the cognitive presence (Kovanović et al., 2016; Neto et al., 2018).

Appendix A. Scaffolding intervention

A.1. Control group

For the participation mark (10% of the final course grade), you are expected to participate actively in the presentations of your peers. Participation in a peer's presentation will not be considered just posting a general comment (e.g., "how great the presentation was" or "how you could not understand the voice due to recording"). To develop a constructive discussion around the presented topics, please, make sure that you understand the paper presented by your peers, provide your peers with feedback about their presentation, and post questions related to your peers' presentation and connected ideas on which you can build your research in the following course assignments.

A.2. Treatment group

For the participation mark (10% of the final course grade), you are expected to participate actively in the presentations of your peers. Participation in a peer's presentation will not be considered just by posting a general comment (e.g., "how great the presentation was" or "how you could not understand the voice due to the poor audio recording"). Your participation needs to be about the content being presenting with the following three levels (from the lowest to the highest quality):

i) clarification question — asking about some uncertain parts of the paper being presented;
ii) synthesis question — asking a question that connects the topics of the presentation at hand with another peer-reviewed paper and its results covered either in the study guide, presentation of another student, or a peer-reviewed research publication;
iii) innovation question — asking or proposing a novel research topic by making use of the results presented in the paper at hand to draw ideas that are formulating a research problem/challenge. Preferably, the result of a discussion triggered by such a question might result even in the problem formulation of the research to be done in the final assignment of the course.

Every student is expected to have at least two posts in category 2 and one post in category 3. The reset of the questions can fit into category 1.

A.3. Epistemic network analysis: an example

To exemplify the application of ENA, we summarize the work proposed by Gašević et al. (2015), where ENA was adopted to explain the relationship between course topics and cognitive presence phases. The study in this example involved students from two different groups (control and intervention) which are denoted as blue and red groups here. The meaning of the groups is not necessary for the understanding of the example. In this ENA example, both the unit of analyses and the stanza were individual student participants. Fig. B.6b presents a network graph, where it is possible to analyze the relationship between the codes. In this example, the codes are the course topics and cognitive presence phases. This figure shows the mean network of the group blue, represented by the blue square in Fig. B.6a. Similar networks can be presented for each individual participant in the sample or any way the participants can be grouped. A svd defines each axis in the graph with its respective variance, which represents how much the axes explain the data Hendler and Shrager (1994). In this example, the Axis-X and Axis-Y represent 30% and 18% of the variance in data, respectively. There are three main aspects to consider in this graph:

i) The size of the nodes shows how important each code is for this group;
ii) the strength of the connection between two codes represents how frequent is the co-occurrence of these codes;
iii) the place where the node was plotted express how correlated the codes are.

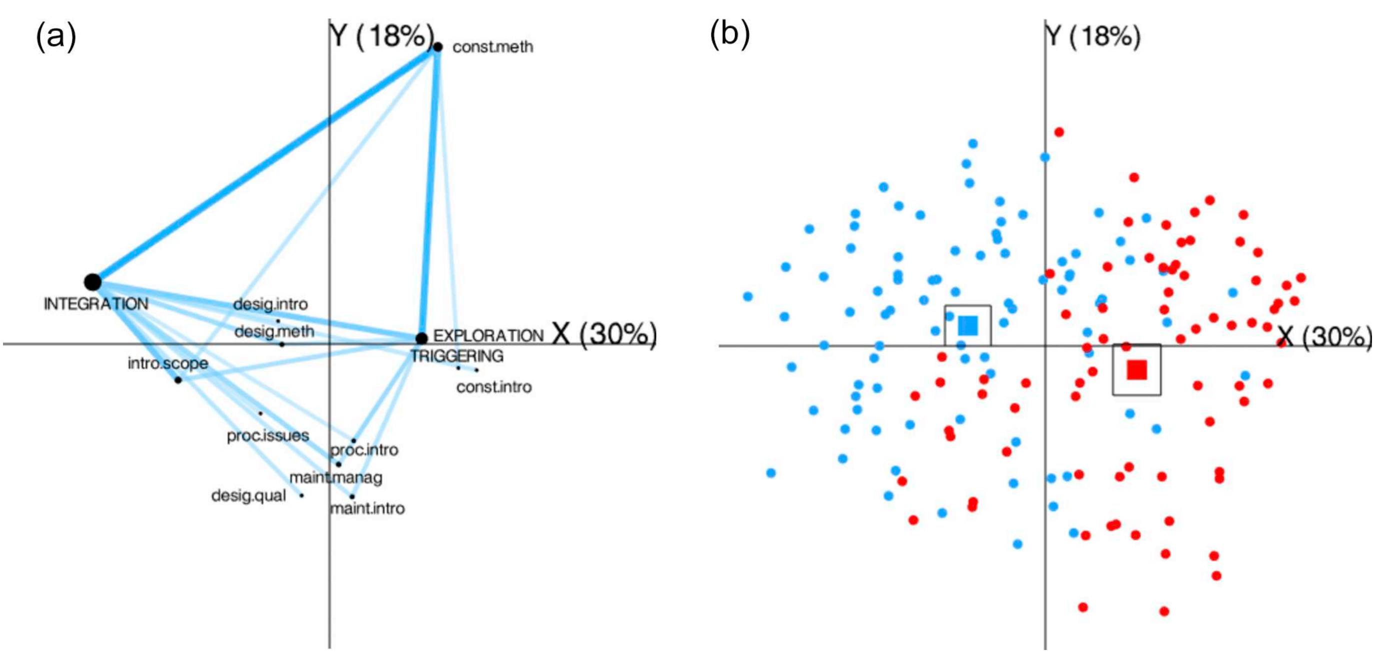

Fig. B.6. ENA example.

Fig. B.6a shows the projection graph, in which each node represents a unit of analysis (in this case a student), which are divided into two groups (blue and red). That is, each individual student network is reduced into a single node that is referred to as centroid. In general sense, centroids can be understood as natural points of gravity for a network. The squares in the network are the mean values of each of the two groups (blue and red) with the confidence interval (black line). This allows for statistical comparison between groups across each axis (i.e., svd dimension). It is important to notice that this graph was projected under the same axes as in Fig. B.6b. In other words, we can use the nodes from Fig. B.6b to better understand the position of each student in Fig. B.6a.

Finally, Fig. B.7 is an example of a subtraction network. This graph is similar to the network graph presented before. However, it compares two groups at the same time. In this case, it analyzed the mean networks of group blue and red. It is possible to see which groups made stronger connections between different codes.

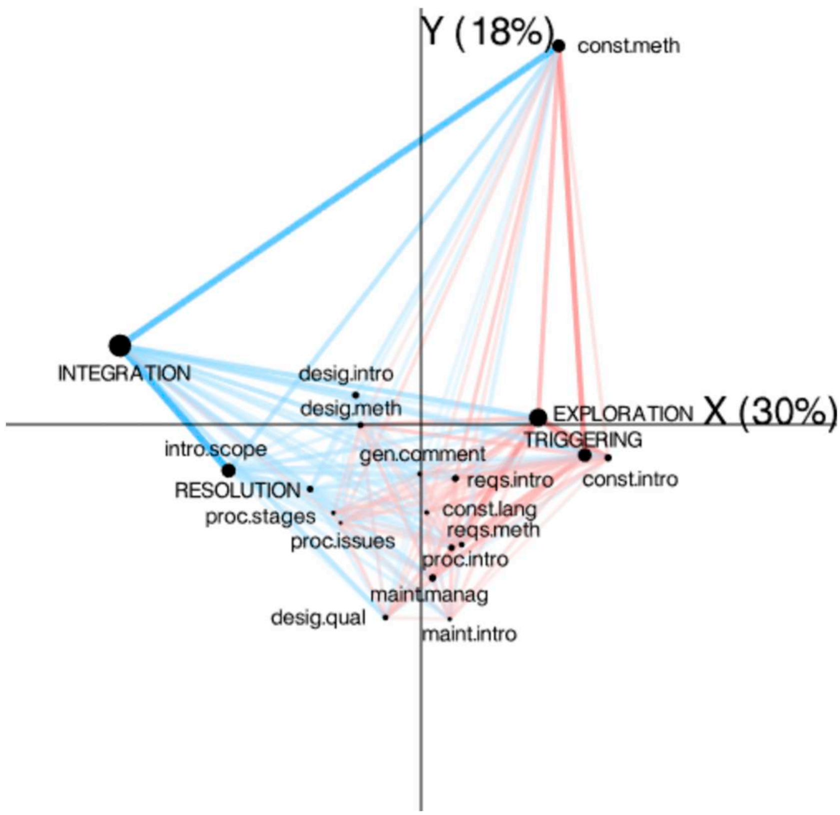

Fig. B.7. Subtraction graph.

Additionally, ENA also provides a representation of how the behavior of different groups changes over time. The trajectory graph, an example can be seen in Fig. 5b plots a unit of time (in this case weeks) as nodes and how the group of student changed their behavior over the time as links.

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