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Exploring the relationships between interaction measures and learning outcomes through social network analysis: the mediating role of social presence

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Abstract

This research aimed to explore (1) the characteristics and patterns of student interactions on online discussion boards throughout a course using social network analysis (SNA) and (2) the mediating effect of social presence, as the underlying mechanism, on the relationship between these interactions and students' learning outcomes. Eighty-four college students from four classes of a single course responded to an online survey asking about their perceptions of social presence, perceived learning achievement, and course satisfaction. Students' discussion threads were analyzed using SNA. The results confirmed that social presence mediates relationships between interaction measures and learning outcomes. This research also found that SNA can be a useful tool to monitor the dynamic characteristics and patterns of online discussion interactions among students and support instructors to implement immediate and relevant instruction.

Keywords: Social presence, Interaction, Learning outcome, Asynchronous online discussion, Social network analysis (SNA)

Introduction

Since Computer Supported Collaborative Learning (CSCL) was introduced in higher education, asynchronous discussion boards have been the main location of teaching and learning in online environments. Asynchronous discussions allow students to interact with each other and co-construct knowledge by sharing social and intellectual communications. Particularly, interaction on discussion boards has been recognized as a critical factor that influences the success of online learning (Dado & Bodemer, 2017; Liu et al., 2022). Moore (2014) confirmed that interaction among students is an important predictor of their success and satisfaction with their courses by analyzing discussion board posts from students in online undergraduate courses. Indeed, previous research has shown that students' engagement and interaction on asynchronous online discussion boards have a substantial impact on their successful participation in learning,

accomplishment, and satisfaction (Kožuh et al., 2015; Moore, 2014; Pena-Shaff & Altman, 2015; Shelton et al., 2017).

However, most previous research has measured interaction from an outcome perspective, based on a survey or content analysis, rather than a dynamic interaction process. More recently, there have been some attempts to analyze the dynamic processes and patterns of students' interactions on discussion boards from a network perspective. Correspondingly, Ouyang and Scharber (2017) emphasized the importance of a process-oriented perspective to explore the development and attributes of an online learning community.

Social Network Analysis (SNA), a method of data analysis used to explore relations among social entities and their effects (Wasserman & Faust, 1994, p. 3), has received attention from many researchers as a useful way to analyze students' interactions from a process perspective (Jiang et al., 2014). Haythornthwaite (2005) also stated that SNA can be used to explore the complexities of relations and connections between members of a network. The promising effects of SNA in educational research have driven researchers to conduct studies on students' interactions, relationships, and involvement in online discussions throughout a course. However, although many researchers have stressed that interaction is important for the success of online discussions, there is no clear consensus about the relationship between interaction measures and learning outcomes (Kent et al., 2016).

Some researchers have underlined that the authenticity and quality of interaction matter; it is not just about interacting with peers or instructors (Yen et al., 2022). In order to make interactions meaningful and impact learning outcomes, students need to present themselves as real people and feel that they are communicating with real peers and instructors. However, research has not yet fully identified the mediating role of social presence: students' ability to present themselves as real people in online learning and feel socially connected to others in the online community. Given the gaps in the literature, this research aims to explore the effects of SNA interaction measures on learning outcomes, as well as the mediating role of social presence as the underlying mechanism.

Theoretical background

SNA as a means of measuring interaction

SNA is a technique used to analyze patterns of interaction and relationships between actors in a network (Dado & Bodemer, 2017; Wasserman & Faust, 1994). Actors in asynchronous online learning contexts include instructors, students, classes, or learning materials (Dado & Bodemer, 2017). According to Luo et al. (2019), posting and responding are the primary interactive activities that lead to knowledge construction within a discussion network.

The relational ties of interactions can be collected by tracing digital data (e.g., chat logs) or directly checking who communicated with whom on discussion posts (Dado & Bodemer, 2017).

Recently, researchers have increasingly used SNA metrics to better understand the dynamic features and process of students' interaction and engagement on discussion boards. For example, Ergün and Usluel (2016) explored how students' social network structures change over time based on the instructor's participation in the online learning

environment. They discovered that, in four out of six groups, the highest density of interaction occurred during the week when the instructor participated in the discussion. Ergün and Usluel (2016) also found that the students at the core or the periphery of the discussion network changed over time and based on the instructor's engagement.

Contrary to this, Stepanyan et al. (2014) reported that discussion participants with a high degree of centrality during the initial stage of an online course are more likely to be at the core at the end of the course. Sundararajan (2010) analyzed students' interactions in online chats and on bulletin boards using SNA. In the study, the scholar demonstrated that students who were central in the chat networks tended to maintain their centrality in the network, while other students emerged to have central roles as the discussion progressed.

Research on SNA interaction measures and online learning outcomes

With growing interest in using SNA to explore the dynamic characteristics and patterns of interactions in online discussions, many researchers have studied the relationships between SNA interaction measures (e.g., outdegree, indegree, betweenness, closeness, or eigenvector centrality) and students' cognitive or affective learning outcomes.

For cognitive learning outcomes, there have been mixed results for the different SNA interaction indices. However, many studies have validated the association between interaction measures and cognitive learning outcomes, including actual final scores and learning performance. Jo et al. (2017) revealed that outdegree and indegree centrality had predictive effects on students' final scores, with an explanatory power of approximately 68.9% ($F = 47.631, p = 0.000$). Outdegree centrality means the number of outgoing links initiated by an actor and indegree centrality refers to the number of links that an actor received from other actors of the network (Jo et al., 2017). Through multiple regression analysis, Kim et al. (2015) demonstrated that students' indegree ($B = 0.240, p = 0.000$) and outdegree centrality ($B = 0.233, p = 0.000$) predicted their final scores, accounting for around 70% of the variance.

Galikyan and Admiraal (2019) found inconsistencies in the predictive effects of outdegree and indegree centrality on student final grades: outdegree centrality had a significant predictive effect on students' final grades ($B = 13.30, p = 0.021$), while indegree centrality had no significant effect ($B = -26.34, p = 0.092$). In contrast, Liu et al. (2018) found no significant positive correlation between outdegree centrality and learning achievement but confirmed a significant positive correlation between indegree centrality and academic achievement ($r_s = 0.368, p < 0.01$).

Furthermore, Ye and Pennisi (2022) explored the relationship between interaction patterns (closeness and outdegree centrality) and students' learning performance. The results showed significant positive correlations between both outdegree and closeness and learning performance. Ye and Pennisi (2022) also proved that outcloseness, which is calculated by the length of shortest paths that an actor reaches to other actors, has predictive effects on students' learning performance with regression analysis. Notably, Saqr et al. (2022) performed a meta-analysis and a systematic review of prior studies to determine the relationships between SNA interaction indices and students' learning achievement in CSCL. The results revealed that both outdegree and indegree centrality had positive correlations with students' learning achievement in all of the reviewed

studies. Although the results need to be interpreted carefully due to the high heterogeneity of the correlation coefficient values and the small number of studies reviewed, they confirmed that outdegree and indegree centrality are important factors, which are closely related to students' learning achievement.

On the other hand, relatively little research has been conducted to investigate the relationships between SNA interaction measures and affective learning outcomes. Furthermore, previous studies have yielded conflicting results. For example, in a study by Russo and Koesten (2005), outdegree and indegree centrality did not have any substantial impact on affective learning outcomes. However, Lowes et al. (2007) reported that network analysis measures, including density, reciprocity, and network centralization rankings, showed high correlations with students' satisfaction.

Given the conflicting results of prior studies on the relationships between SNA interaction measures and online learning outcomes, more studies are required to understand how these constructs relate (Dado & Bodemer, 2017; Saqr et al., 2022).

The mediating role of social presence

Social presence refers to participants' ability to project themselves as real people in online learning and feel socially and emotionally connected to others in the community (Garrison et al., 1999). Previous researchers have suggested that interacting with others contributes to cultivating social presence (Hauck & Warnecke, 2013; Kehrwald, 2010). Indeed, studies have explored the associations between students' interaction on online discussion forums and social presence. Shea et al. (2014) revealed that a student's network centrality is closely correlated with his or her social presence. Specifically, students with higher social presence indicators tend to be located near the center of the network. Kyei-Blankson et al. (2016) reported that learner–learner, learner–instructor, and learner–content interactions have significant correlations with social presence ($p < 0.05$). They also found that a model including all sub-components of interaction (learner–instructor, learner–learner, learner–content) and presence (social, cognitive, teaching) explained 86% of students' ratings of their learning experiences.

Tirado et al. (2012) analyzed students' social presence on asynchronous discussion forums through content analysis. This research revealed that cohesion and centralization indices had a significantly positive influence on social presence. Recently, Yen et al. (2022) showed that interaction measures (indegree, outdegree, betweenness centrality, closeness centrality, eigenvector centrality) had significant positive correlations with social presence.

However, Satar and Akcan (2018) found inconsistent results regarding the relationships between social presence and interaction measures in different semesters. They investigated the relationships between students' social presence levels and SNA measures over two semesters. Satar and Akcan showed that all SNA measures had significant relationships with interactive indicators of social presence in the fall semester, while no significant relations were found in the spring semester.

Furthermore, social presence has been shown to be a predictor of students' learning outcomes in online learning environments. For instance, Zhan and Mei (2013) reported that students' social presence had a significant positive effect on their scores and satisfaction with online learning. Alsadoon (2018) showed that it had a significant predictive

effect on learners' satisfaction with mobile learning. In addition, through a meta-analysis, Richardson et al. (2017) confirmed that social presence had a significant positive relationship with students' perceived learning and satisfaction.

To summarize, past studies have regarded social presence as a variable that is closely associated with interaction measures, as well as a predictor of learning outcomes in online environments. Furthermore, some researchers have suggested that social presence may play a more critical role than that of an outcome variable or a predictor; they have paid attention to its role as a mediator (Li et al., 2021; Song et al., 2019). Zhao et al. (2014) also suggested that the optimal level of social presence that emerges from interactions is essential to increase participation, shape the dynamics of interaction, and thus facilitate collaboration and meaningful learning experiences. Through active interaction, students may feel more closely connected socially and have authentic relationships with their classmates and instructors. This enhanced social presence can lead to successful learning experiences and results. Based on the findings of previous research, this study explored the mediating effect of social presence, as the underlying mechanism, on the relationships between SNA interaction measures and learning outcomes.

Research questions

The primary purpose of this study was to explore the characteristics and patterns of students' interactions on online discussion boards using SNA, as well as the connections between the SNA interaction measures and students' learning outcomes. This study also investigated the mediating effect of social presence, as the underlying mechanism, on the relationships between interaction measures and learning outcomes. Specifically, the research questions were as follows:

RQ1. What do students' online discussion interactions characteristics and networks look like?

- a. Do students' positions in the interaction network (outdegree and indegree centrality) change throughout the course?
- b. Does the students' interaction network change throughout the course?

RQ2. How are students' SNA interaction measures (outdegree and indegree centrality) and social presence related to learning outcomes (perceived learning achievement and satisfaction)?

RQ3. How does social presence mediate the relationships between SNA interaction measures (outdegree and indegree centrality) and learning outcomes (perceived learning achievement and satisfaction)?

Methods

Context and participants

The participants of this study were eighty-four college students majoring in elementary education in South Korea. Specifically, they were recruited from four classes of a single course, Introductory Educational Technology. All four classes had the same course structure and tasks, which included lecture videos, text-based online discussions, individual assignments, and group projects on a learning management system (LMS).

The students in this course were expected to participate in all five discussion forums. Most participants in this research had no prior experience with asynchronous online discussions and were participating in the forums for the first time. The discussion forums covered various topics and questions about instructional design, development, and implementation (see Table 1).

Each student was required to develop initial posts concerning a given topic and then interact with other students and instructors by offering two additional posts or comments to deepen and advance the conversation on the discussion board. Their discussion scores, which were weighted according to frequency (e.g., excellent: 3 or more postings, well distributed throughout the week; fair: 2 postings, not distributed throughout the week) and quality (e.g., excellent: postings consistently related to the discussion questions with relevant references; poor: postings unrelated to the discussion questions) accounted for 30% of their final course grades. A grading rubric for discussion board participation was given to all the students at the beginning of the semester. Throughout the discussions, the instructor participated as a peer and a facilitator to encourage the students to share their ideas with others and build on them. The demographic information of participants was as follows: fourteen students (Male: 7; Female: 7) in Class A and 23 students in Class B (Male: 9; Female: 14) participated in the study. Classes C and D had 21 (Male: 8; Female: 13) and 26 (Male: 13; Female: 13) students, respectively.

Data collection and measurements

The data for this research were collected from two different sources: archived student discussion threads and an online survey. In order to analyze the dynamic characteristics and patterns of student interaction on the discussion board, the researcher read the content of discussion postings and determined who talked to whom on each post. Based on the results of the analysis, adjacency matrices were created. The rows and columns represent who commented on whose posts.

Next, an online survey was conducted to assess the students' perceptions of social presence, learning achievement, and course satisfaction. To assess their perceptions of social presence, this study used the social presence items from the Community of Inquiry (CoI) framework survey developed by Arbaugh et al. (2008), which comprise nine items divided evenly into three subcategories: affective expression, open communication, and group cohesion. The CoI survey was chosen because it has been the most widely used in previous research to measure social presence in online courses (Caskurlu, 2018; Cho & Tobias, 2016; Cho et al., 2022; Kozan & Richardson, 2014; Lim & Richardson, 2021; Saadatmand et al., 2017). Previous research confirmed that the social

Table 1 Topics and questions for each discussion forum

Week	Discussion topics	Discussion types
Week 2	Digital education and the Fourth Industrial Revolution	Open-ended discussion
Week 3	Learner and environment analysis for instructional design	Case-based discussion
Week 5	Implementing ARCS strategies	Case-based discussion
Week 6	Objectivism vs. constructivism instructional design	Pros/cons discussion
Week 7	Strategies for successful flipped learning	Case-based discussion

presence items have high levels of reliability and validity (Arbaugh et al., 2008; Caskurlu, 2018; Heilporn & Lakhali, 2020). This study also yielded an internal reliability of 0.92 for social presence.

Students' perceived learning and satisfaction with the online course were measured using three items each. The items were adapted from Kim's (2013) study. One sample item for perceived learning achievement is, "I gained a good understanding of the basic knowledge of the subject area." A sample item for satisfaction is, "I would recommend this course to other students."

Data analysis

For the first research question, SNA was used to analyze the properties and structural patterns of students' interactions in online discussions. Specifically, outdegree and indegree centrality were assessed to identify how students' interaction positions in the discussion changed throughout the course. Outdegree centrality refers to the degree of outgoing activity initiated by an actor (Tirado et al., 2012). Indegree centrality indicates the degree of interaction directed toward an actor (Ouyang & Scharber, 2017). According to Haythornthwaite (2005), actors with high outdegree centrality are likely to have a high level of influence while actors who show high indegree centrality are individuals with high prestige in the network, as they are chosen by other people most often.

Furthermore, this study also measured the density, reciprocity and outdegree and indegree centralization of the discussion networks of each class. Density, which ranges from 0 to 1, is calculated by dividing the total number of ties in a discussion network by the number of possible ties (Carolan, 2013). A higher density value means the network is more active and cohesive (Dado & Bodemer, 2017). Reciprocity is defined as the ratio of the number of existing links to the number of reciprocal ties, in which there is another tie between the two nodes pointing in the other direction (Pfeil & Zaphiris, 2009). Density must be used and interpreted carefully since the value might be inflated due to the overwhelming effect of a few core members, while the mean of all network members' connections remains low. It is also closely related to network size: larger networks with core actors tend to show lower density than smaller networks (Tirado et al., 2012).

To complement this value, this study also considered outdegree and indegree centralization. A high level of outdegree centralization indicates that a few powerful leaders dominate the outgoing connections with others, whereas high indegree centralization means that a network has an imbalanced distribution of ingoing ties and focuses on a few core members (Goggins et al., 2016, p. 248). UCINET, one of the most well-known social network programs, was used in this research.

For the second and third research questions, this research performed descriptive, correlation, and mediation analyses. The correlation analysis was conducted to explore how students' outdegree and indegree centrality on the discussion boards related to their perceived learning achievement and satisfaction. SPSS 26 was used for the descriptive and correlation analysis. Next, mediation analysis was performed using the PROCESS Macro Model 4 developed by Hayes (2017) to explore whether students' social presence mediates the relationships between SNA interaction measures (outdegree and indegree centrality) and learning outcomes (perceived learning achievement and satisfaction).

Results

Interaction characteristics and network patterns in online discussions

To answer RQ1, this research analyzed the interaction characteristics and structures of online discussion networks. First, students' outdegree and indegree centrality were calculated throughout the course. One result was that in all four classes, specific students tended to maintain a high level of outdegree centrality. In particular, Class A showed a clearer tendency to be dominated by certain actors compared to other classes. Students A6, A12, and A13 in Class A maintained high levels of outdegree centrality throughout the course. Students A12 and A13 were ranked first or second in terms of outdegree centrality for all the weeks of the course.

Similarly, the other three classes had specific core actors (e.g., B9, B10, and B19 in Class B; C17 and C21 in Class C; D3 and D9 in Class D) who had high levels of centrality for most weeks. However, a greater variety of students occupied highly-ranked positions in Classes B, C, and D than in Class A. This shows that Class A was a more fixed or static network than the other classes, in which students' positions changed more frequently. This may be explained by the composition of the students' majors in each class. All the students in Class A were majoring in the same field, while students from different majors were found in the other classes. The students in Class A were likely to have closer face-to-face relationships with each other; therefore, their roles in the discussions might have been predetermined in other courses where they studied together prior to this online course. This factor might have made students' outdegree centrality rank in Class A more static and impervious to change.

On the other hand, it was more likely for various students to be ranked first or second for indegree centrality as shown in Table 2.

Furthermore, this study compared how density, reciprocity, and outdegree and indegree centralization changed throughout the course in the four different classes. The results did not show any notable common trends in terms of density or reciprocity. However, all four classes showed the lowest density in Week 6, in which a pros/cons discussion took place (see Table 3). In addition, it was interesting to see that when the density value was the highest, reciprocity was the highest in all four classes. This implies that more active and cohesive discussion networks are likely to have more mutual and bilateral relations.

Next, this study explored the values of outdegree and indegree centralization throughout the course. Overall, outdegree centralization showed higher values than indegree centralization most weeks except for Class 2 (see Table 4). This indicates that particular students acted as the centers who controlled or dominated the activity of sending messages, while most students received a similar number of ingoing messages.

Correlation analysis of students' SNA interaction measures, social presence, and learning outcomes

For RQ2, descriptive statistics, including means and standard deviations, were calculated to measure students' outdegree and indegree centrality, social presence, and perceived learning achievement and satisfaction. Next, Spearman's correlation

Table 2 Change of outdegree and indegree centrality on weekly discussion boards

(Class A)					
Rank	Week 2	Week 3	Week 5	Week 6	Week 7
Outdegree centrality					
1	A12 (0.267)	A13 (0.267)	A6 (0.167)	A13 (0.200)	A13 (0.400)
2	A13, A6 (0.167)	A12 (0.200)	A1, A12, A13 (0.133)	A12 (0.167)	A12 (0.267)
Indegree Centrality					
1	A9, A10, A11, A13 (0.133)	A12 (0.200)	A1, A6 (0.200)	A5, A13 (0.133)	A10, A11 (0.333)
2	A1, A2, A5, A6, A12 (0.100)	A11 (0.167)	A10 (0.167)	A1, A3, A6, A10, A12 (0.100)	A3, A12 (0.267)
(Class B)					
Rank	Week 2	Week 3	Week 5	Week 6	Week 7
Outdegree centrality					
1	B9 (0.128)	B19 (0.115)	B24 (0.173)	B9, B10, B20 (0.115)	B10, B19 (0.154)
2	B19 (0.115)	B10 (0.077)	B10 (0.154)	B4, B14, B19 (0.077)	B9, B25 (0.115)
Indegree centrality					
1	B11 (0.115)	B11 (0.103)	B19, B25 (0.154)	B13 (0.154)	B4 (0.173) B2, B19, B26 (0.115)
2	B9 (0.103)	B21 (0.090)	B24 (0.135)	B20 (0.115)	B9, B10, B25 (0.096)
(Class C)					
Rank	Week 2	Week 3	Week 5	Week 6	Week 7
Outdegree centrality					
1	C17, C25 (0.098)	C27 (0.161)	C21 (0.179)	C21 (0.107)	C10, C21, T1 (0.125)
2	C13, C21, C27 (0.080)	C17 (0.143)	C10, C13 (0.143)	C12, C22 (0.095)	C6, C13 (0.107)
Indegree centrality					
1	C17 (0.098)	C20 (0.125)	C27 (0.143)	C17 (0.095)	C10, C18 (0.143)
2	C13 (0.089)	C12, C17, C27, C28 (0.107)	C21 (0.125)	C10, C21, C22 (0.083)	C6, C15, C20 (0.107)
(Class D)					
Rank	Week 2	Week 3	Week 5	Week 6	Week 7
Outdegree centrality					
1	D3, D9, D19 (0.115)	D3 (0.135)	D11 (0.115)	D3, D16, D19, D23, D25 (0.154)	D5 (0.154)
2	D11, D16, D17, D20 (0.096)	T1 (0.115)	D5, D18 (0.096)	D5, D9, D10, D20, D21, T1 (0.115)	D9, D21 (0.115)
Indegree centrality					
1	D9, D26 (0.115)	D2, D3 (0.115)	D3, D4, D23 (0.096)	D19 (0.192)	D5 (0.115)
2	D5, D7, D10, D11 (0.096)	D16, D18, D20 (0.096)	D1, D10, D14, D15, D24 (0.077)	D16, D23, D26 (0.154)	D2, D4, D12, D13, D20 (0.096)

analyses were conducted to assess possible relationships between the learning outcome variables and the other variables (see Table 5).

The results confirmed that there was a relatively high correlation between outdegree and indegree centrality ($r_s = 0.757, p < 0.01$). For the dependent variables, students' social presence showed a relatively higher correlation with learning outcomes ($r_s = 0.609, p < 0.01$ for perceived learning achievement; $r_s = 0.544, p < 0.01$ for

Table 3 Changes in density and reciprocity on weekly discussion boards

Class	Week 2 (Open-ended)	Week 3 (Case-based)	Week 5 (Case-based)	Week 6 (Pros/Cons)	Week 7 (Case-based)
Density					
Class 1	0.171	0.188	0.158	0.129	0.129
Class 2	0.130	0.110	0.137	0.095	0.105
Class 3	0.135	0.139	0.117	0.094	0.103
Class 4	0.117	0.097	0.093	0.071	0.111
Reciprocity					
Class 1	0.242	0.364	0.310	0.292	0.148
Class 2	0.468	0.426	0.627	0.288	0.451
Class 3	0.642	0.738	0.532	0.520	0.355
Class 4	0.577	0.388	0.300	0.282	0.418

Table 4 Changes in outdegree and indegree centralization on weekly discussion boards

Class	Week 2 (Open-ended)	Week 3 (Case-based)	Week 5 (Case-based)	Week 6 (Pros/Cons)	Week 7 (Case-based)
Outdegree centralization					
Class 1	0.316	0.369	0.187	0.289	0.289
Class 2	0.265	0.166	0.098	0.141	0.210
Class 3	0.119	0.189	0.138	0.162	0.152
Class 4	0.118	0.139	0.143	0.086	0.204
Indegree centralization					
Class 1	0.102	0.227	0.258	0.147	0.218
Class 2	0.185	0.166	0.178	0.220	0.210
Class 3	0.119	0.115	0.138	0.125	0.189
Class 4	0.118	0.139	0.104	0.126	0.124

Table 5 Descriptive statistics and Spearman's correlations

	1	2	3	4	5
1. nOutdegree	1	0.757**	0.319**	0.346**	0.258*
2. nIndegree	0.757**	1	0.270*	0.236*	0.235*
3. SP	0.319**	0.270*	1	0.609**	0.544**
4. Achievement	0.346**	0.236*	0.609**	1	0.768**
5. Satisfaction	0.258*	0.235*	0.544**	0.768**	1
Mean	0.110	0.115	4.116	4.532	4.631
SD	0.736	0.567	0.767	0.497	0.515

* $p < 0.05$. ** $p < 0.01$

SP = social presence; SD = standard deviation

satisfaction) than it did with outdegree and indegree centrality. Furthermore, outdegree centrality showed higher correlations with social presence ($r_s = 0.319, p < 0.01$), perceived learning achievement ($r_s = 0.346, p < 0.01$), and satisfaction ($r_s = 0.258, p < 0.05$) than indegree centrality did.

Table 6 The mediating effect of social presence on the relationship between outdegree and perceived learning achievement

	B (Coefficient)	se	t	p	LLCI	ULCI
Outdegree → SP	3.428	1.088	3.150	0.002	1.263	5.593
SP → Achievement	3.246	0.061	5.342	0.000	0.204	0.446
Outdegree → Achievement	1.399	0.634	2.207	0.030	0.138	2.661
Total effect	2.512	0.692	3.630	0.001	1.135	3.889
Direct effect	1.399	0.634	2.207	0.030	0.138	2.661
Indirect effect	1.113	0.408	–	–	0.466	2.056

Table 7 The mediating effect of social presence on the relationship between outdegree and satisfaction

	B (Coefficient)	se	t	p	LLCI	ULCI
Outdegree → SP	3.428	1.088	3.150	0.002	1.263	5.593
SP → Satisfaction	3.120	0.068	4.620	0.000	0.178	0.446
Outdegree → Satisfaction	0.864	0.704	1.227	0.224	– 0.537	2.265
Total effect	1.933	0.743	2.601	0.011	0.455	3.411
Direct effect	0.864	0.704	1.227	0.224	– 0.537	2.265
Indirect effect	1.069	0.401	–	–	0.431	1.983

Mediating effect of social presence—outdegree centrality and learning outcomes

This research conducted a mediation analysis to explore the mediating effect of social presence on the relationship between outdegree centrality and perceived learning achievement. First, students’ outdegree centrality (independent variable) showed a predictive effect on their social presence (mediator; $B = 3.428, p = 0.002$) and perceived learning achievement (dependent variable; $B = 1.399, p = 0.030$). Social presence also showed a predictive effect on perceived learning achievement ($B = 3.246, p = 0.000$). Next, a bias-corrected bootstrap 95% CI indicated that the indirect effect of social presence was significant ($B = 1.113, SE = 0.408, 95\% CI, [0.466, 2.056]$) and thus mediated the relationship between outdegree centrality and learning achievement (see Table 6).

Another mediation analysis was performed to measure the mediating effect of social presence on the relationship between outdegree centrality and satisfaction. The results showed that students’ outdegree centrality (independent variable) had a significant predictive effect on social presence (mediator; $B = 3.428, p = 0.002$), while it did not have any significant effect on satisfaction (dependent variable; $B = 0.864, p = 0.224$). Finally, social presence (mediator) had a significant predictive effect on satisfaction ($B = 3.120, p = 0.000$). A bias-corrected bootstrap 95% CI confirmed that the indirect effect of students’ outdegree centrality on satisfaction was significant ($B = 1.069, SE = 0.401, 95\% CI, [0.431, 1.983]$). This implies that social presence mediated the relationship between outdegree centrality and students’ satisfaction (see Table 7).

Mediating effect of social presence—indegree centrality and learning outcomes

Table 8 presents the results of analyzing the effect of social presence as a mediator of the relationship between indegree centrality and learning achievement. Students’ indegree

Table 8 The mediating effect of social presence on the relationship between indegree and perceived learning achievement

	B (Coefficient)	se	t	p	LLCI	ULCI
Indegree → SP	4.102	1.424	2.880	0.005	1.268	6.935
SP → Achievement	3.590	0.062	5.800	0.000	0.236	0.482
Indegree → Achievement	0.431	0.838	0.514	0.609	− 1.236	2.098
Total effect	1.903	0.944	2.016	0.047	0.025	3.781
Direct effect	0.431	0.838	0.514	0.609	− 1.236	2.098
Indirect effect	1.473	0.533	–	–	0.484	2.581

Table 9 The mediating effect of social presence on the relationship between indegree and satisfaction

	B (Coefficient)	se	t	p	LLCI	ULCI
Indegree → SP	4.102	1.424	2.880	0.005	1.268	6.935
SP → Satisfaction	3.210	0.067	4.779	0.000	0.187	0.455
Indegree → Satisfaction	0.799	0.909	0.878	0.382	− 1.010	2.608
Total effect	2.116	0.975	2.170	0.033	0.176	4.055
Direct effect	0.799	0.909	0.878	0.382	− 1.010	2.608
Indirect effect	1.317	0.502	–	–	0.402	2.374

centrality (independent variable) had a significantly positive predictive effect on social presence (mediator; $B = 4.102$, $p = 0.005$). Students' social presence also had a significant association with perceived learning achievement ($B = 3.590$, $p = 0.000$), while no significant effect between indegree centrality and learning achievement was found ($B = 0.431$, $p = 0.609$). The result of a bias-corrected bootstrap 95% CI showed that indegree centrality had a significant indirect effect on learning achievement ($B = 1.473$, $SE = 0.533$, 95% CI, [0.484, 2.581]). This confirms that social presence mediated the relationship between indegree centrality and students' perceived learning achievement, while indegree centrality had no direct effect on learning achievement.

Finally, the results of the analysis of social presence as a mediator of the relationship between indegree centrality and satisfaction are shown in Table 9. First, indegree centrality (independent variable) had a significant association with social presence (mediator; $B = 4.102$, $p = 0.005$) but did not show any significant predictive effect on students' satisfaction ($B = 0.799$, $p = 0.382$). Next, social presence had a significant association with students' satisfaction ($B = 3.210$, $p = 0.000$). The result of a bias-corrected bootstrap 95% CI indicated that students' indegree centrality had a significant indirect effect on satisfaction ($B = 1.317$, $SE = 0.502$, 95% CI, [0.402, 2.374]), supporting the idea that social presence mediates the relationship between students' indegree centrality and satisfaction. Indegree centrality had no significant direct effect on satisfaction.

Discussion and implications

This study explored the characteristics and patterns of students' interactions on discussion boards using an SNA approach. Furthermore, it examined the effects of SNA interaction measures on learning outcomes, as well as the mediating effect of social presence

as the underlying mechanism. First, this research confirmed that students' levels of out-degree and indegree centrality correlated significantly with their social presence, perceived learning achievement, and course satisfaction. Similarly, previous research also found that centrality measures were significantly associated with learning outcomes (Galikyan & Admiraal, 2019; Jo et al., 2017; Kim et al., 2015; Saqr et al., 2022). This implies that active participation (outdegree centrality) and prestige (indegree centrality) in a discussion network are important for students to have high levels of social presence and successful learning outcomes.

Importantly, this research also found that particular students with high levels of out-degree centrality tended to be ranked at the top position consistently throughout the course. Some previous research has also reported that students with a high degree of centrality at the initial stage tend to maintain their core position until the end of the course (Stepanyan et al., 2014; Sundararajan, 2010). In addition, students located at the periphery may be isolated throughout the course unless the instructor provides immediate and intentional intervention. By monitoring students' interaction centrality throughout a course, instructors can prevent students who are located at the margins of the discussion network from remaining passive learners throughout the course. At the same time, instructors can encourage the core members with a high degree of centrality to enhance other learners' social presence and create a positive and active learning atmosphere by encouraging the marginal members to engage in discussion activities (Luo et al., 2019).

Next, this study explored the changes in density, reciprocity, and outdegree and indegree centralization over the duration of the course. No notable changes were found. However, it is important to note that the lowest density for all four classes was found for the discussion forums that included a pros/cons discussion. Density increased slightly for the following discussion forum, which included a case-based discussion. This is a somewhat different result from previous research, which reported that the density of the discussion network showed a slight decrease towards the end of a course (Daradoumis et al., 2004; De Laat et al., 2007). Students might be reluctant or reticent to publicly share their differing viewpoints with other students in an online setting.

The result implies the possibility that the type of discussion question can influence students' interaction patterns in a discussion network. However, interaction tends to be stable or decrease at the end of a course, even without any distinct change in instructional design or intervention. This supports the idea that exploring the effects of various instructional strategies or methods is needed to facilitate or maintain students' interaction and engagement.

The findings of this study suggest that SNA can be a useful tool not only to capture dynamic and relational information about students' interaction characteristics and patterns in discussion networks but also provide hints for immediate and relevant instructional interventions.

However, while many researchers and practitioners have increased interest in analyzing and using social dynamic information from discussion forums (Da Silva et al., 2019; Kim et al., 2015), obtaining centrality remains a challenge. Many researchers still manually identify "who-and-whom" relationships on discussion boards to perform SNA. In addition, although there are a few SNA tools that are built into LMSs, they have limited

functionality and thus do not provide enough information to analyze students' dynamic relations and interactions (Hernández-García & Conde-González, 2016). In order to utilize centrality measures more actively and practically, researchers and developers need to study how to extract SNA information from an LMS automatically and easily. They can thereby support instructors to monitor students' interaction and participation immediately.

In addition, the results of the current study unveiled that social presence mediates the relationships between centrality measures and perceived learning outcomes and satisfaction. In particular, social presence fully mediated the relationships between both outdegree and indegree centrality measures and learning outcomes, except for the relationship between students' outdegree centrality and perceived learning achievement.

In other words, neither outdegree nor indegree centrality measures had direct effects on learning outcomes (except for the direct effect of outdegree centrality on perceived learning achievement). This implies that students who exhibit high participation (outdegree centrality) and prestige (indegree centrality) can enhance their perceived learning achievement or satisfaction by increasing their social presence. The results of this research support the notion that social presence is important to achieve successful online learning experiences and outcomes.

Although no empirical research has directly explored the role of social presence as a mediator of the relationships between centrality measures and learning outcomes, previous research has determined that it contributes considerably to meaningful and successful learning outcomes for students (Alsadoon, 2018; Richardson et al., 2017; Zhan & Mei, 2013). Furthermore, several researchers have revealed its mediating effect on the relationships between various variables and learning outcomes. Li et al. (2021) identified that social presence fully mediates the relationship between human-to-human interactivity and satisfaction. Song et al. (2019) found that it fully mediates the relationships between teacher self-disclosure and teacher–student relationship satisfaction.

Given the importance of social presence as a mediator or factor with a direct effect on learning outcomes, instructors and instructional designers need to focus on ways to promote social presence. In previous studies, researchers have proposed a variety of strategies to increase social presence, such as icebreaker and orientation activities, digital storytelling, audio/video feedback, individual and detailed feedback, synchronous sessions, introduction videos, using emoticons, sharing personal stories or humor, and embedding social media platforms in online courses (Gurjar, 2019; Izmirli & Izmirli, 2019; Lowenthal & Dunlap, 2018). Researchers and practitioners need to make an effort to apply relevant strategies to facilitate students' social presence.

Conclusion

The current study aimed to investigate the characteristics and patterns of student interactions on online discussion boards using an SNA approach. It also explored the mediating effect of social presence, as the underlying mechanism, on the relationships between interaction measures and learning outcomes.

Along with previous studies, the current study demonstrated the critical role of social presence to improve students' successful online learning experiences and outcomes. Additionally, its results confirmed the potential usefulness of SNA as a tool to capture

the dynamic characteristics and patterns of students' interactions in online discussions and help instructors provide immediate and relevant instructional interventions.

Of course, this research has some limitations. First, the participants in this study were all undergraduate students from four classes of the same course, so its findings cannot be generalized to other learning contexts. Next, this study measured students' perceived social presence, learning achievement, and satisfaction through a survey. The survey data depended on students' subjective perceptions. Their actual learning outcomes or social presence may be different from their perceptions. Future research could measure students' social presence and learning outcomes using various datasets and methods. For example, it could consider collecting students' actual grades or measuring actual social presence by analyzing the content of discussion threads.

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Author contributions

The author made contributions to the conception and design of the work; data collection, analysis and interpretation; writing the first draft of the manuscript; revising the first draft. The author finally read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The author declare that they have no competing interests.

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