Quantifying Social Presence in Online-Based Learning: A Statistical and Pedagogical Analysis of Indicators from Social Network Analysis

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Abstract
Social presence is one key factor for successful learning in socio-constructivist learning environments, such as in online-courses based on the Community of Inquiry Framework. Teachers need easily interpretable and pedagogically relevant information to monitor social presence and to intervene if needed while a course is running. Social network analysis is a promising method to provide this information, yet it is unclear which indicators are most appropriate for this aim. This study aimed to identify and evaluate indicators derived from social network analysis, which could quantify social presence and provide pedagogically relevant information to teachers. 3,546 postings from different modules and study groups (n = 49) of an online-based Master's course were manually coded. Egocentric measures were calculated from social network analysis. Path models were developed to analyze which indicators from social network analysis were statistically meaningful measures of social presence. The course of these indicators was analyzed across the modules and statistically evaluated using the Friedman test. Out of 13 possible indicators, six indicators were found to be statistically and pedagogically relevant (Ties, Density, Efficiency, nBroke, Out- & In-closeness). These indicators showed high regression weights in the path models and the progression across multiple time points was identified to be statistically significant ($p < .001$). Literature analysis and pedagogical considerations showed that these indicators might provide an appropriate and real-time overview of students' social presence. We identified indicators that allow to measure social presence and provide meaningful information for teachers in real time by using log data from learning management systems. Further research will now focus on implementing the findings in a teacher dashboard.

Keywords: Community of Inquiry, social presence, social network analysis, higher education, learning communities, distance education

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Over the past decades, online learning has become increasingly popular in higher education, with approximately one-third of U.S. students engaging in distance education courses during the 2018–2019 academic year (National Center for Education Statistics, 2021). This increase continued as the COVID-19 pandemic prompted a widespread shift to online learning. Similarly, there is a noticeable shift to online course participation across European states (Eurostat, 2022). The acceleration of the online delivery mode has highlighted the need for a nuanced understanding of the multifaceted challenges it raises for teaching and learning. For instance, Greenhow et al. (2022) highlight the limited transferability of traditional teaching methods to the online mode, difficulties in encouraging meaningful online participation, and equity concerns (Greenhow et al., 2022). During this transition, an important issue emerged: a decline in learner engagement in distance learning settings (Dumford & Miller, 2018). This led to concerns about addressing unique opportunities and constraints specific to online environments and emphasized the need for a tailored approach (Martin & Borup, 2022).

This study focuses on one crucial aspect that influences the success of online learning, specifically learner engagement that we label "social presence." As defined in the Community of Inquiry Framework (CoIF) by Garrison et al. (1999), social presence refers to "the ability of participants to identify with a group, communicate openly in a trusting environment, and develop personal and affective relationships progressively by way of projecting their individual personalities" (Garrison, 2017, p. 79). In the context of asynchronous online learning environments, where students communicate frequently via text-based forums (Chou et al., 2019), our focus is on understanding and enhancing social presence. At this point, it is worth mentioning that promoting social presence in online learning environments poses a particular challenge due to the lack of physical closeness between participants (Garrison, 2017). In addition, it is often difficult to determine whether social presence should be particularly encouraged, as it can be time-consuming to read all online posts due to the size of the group.

Until now, teachers lack a real-time method to measure social presence in ongoing courses and evaluate it based on pedagogical criteria. Teachers should be enabled to assess social presence during ongoing courses in order to provide adequate feedback, adapt course design when needed, or foster social components to enhance the overall educational experience. To date, social presence has mainly been measured via manual coding (cf. Richardson et al., 2017; Rourke et al., 1999) and surveys (Arbaugh et al., 2008). This process is very labor-intensive and only possible retrospectively. Newer approaches and measurement ideas have already attempted to measure social presence using existing data in the learning management system, such as log data or social network analysis (e.g., Ferreira et al., 2020; Lim, 2023; Maloney et al., 2022; Ruthotto et al., 2020; Zou et al., 2021) data.

What has been missing so far, however, is a precise statistical analysis of which indicators could actually be used to measure social presence and to reassess them accurately on the basis of the theoretical implications of the CoIF. Various studies analyse SNA indicators of social presence (Jimoyiannis et al., 2012; Jo et al., 2017; Lou et al., 2019; Wicks et al., 2015). Consequently, a confirmatory analysis of whether measuring social presence using this data can work and provide valuable pedagogical information in real time is still unclear.

In short, it can be said that accurate, validated, and easily accessible social presence measurement tools would help teachers to assess in real time what is going on in online courses based on the CoIF and thus to respond to students' group behaviour with appropriate teaching methods. We assume that it is possible to track social presence in ongoing online courses using social network analysis (SNA), as the essential feature of SNA is to show patterns of interaction and student engagement during the learning process (De Laat et al., 2007). The challenge now is to find suitable indicators that can be interpreted and validated with a specific pedagogical approach.

Literature Review

First, we will present the CoIF and its social presence in more detail. We will then elaborate on how social presence is mostly measured now and how social network analysis and learning analytics could improve these measurements. Finally, we will present our research questions.

Community of Inquiry Framework

One of the well-known frameworks for designing and evaluating asynchronous online learning environments that particularly addresses the challenges in learners' social presence, among others, is the CoIF developed by Garrison et al. (2001). The CoIF defines three interdependent presences—cognitive presence, teaching presence, and social presence—that together should lead to a valuable educational experience. The framework's authors define cognitive presence "as the extent to which learners are able to construct and confirm meaning through sustained reflection and discourse in a critical Community of Inquiry" (Garrison et al., 2001, p. 11). Teaching presence addresses the responsibilities of designing and organizing online courses, facilitating discourse and direct instruction (Garrison et al., 1999). Social presence was originally defined around learners' interactions, as well as a sense of their real presence projection in the online space (Rourke et al., 1999). Socio-constructivist learning theory, on which the CoIF is based, emphasizes that knowledge is socially constructed through interaction with others (Garrison, 2017). Thus, establishing social presence is of special concern in such learning environments (Kim & Gurvitch, 2020). Plenty of research concerned social presence as a stand-alone construct in over the past 40 years (Lowenthal, 2012). Nevertheless, as an embedded part of the CoIF over the last 20 years, it has been shown that social presence is one of the central aspects of a meaningful educational experience online (e.g., Boston et al., 2019; Richardson et al., 2017; Shelton et al., 2017).

Social Presence as Part of the Community of Inquiry Framework

According to Garrison (2013, p. 11), a community of inquiry is a "learning community where participants collaboratively engage in purposeful critical discourse and reflection (cognitive presence) to construct personal meaning and shared understanding through negotiation." Consequently, students need to engage in critical discourse without being afraid to express their ideas and challenge each other. Therefore, social presence relates to an open and trustful learning atmosphere that requires the establishment of respective social relationships within the community enhanced by teaching presence (Garrison, 2017). Furthermore, social presence relates to full participation in a community of inquiry which is necessary for deep and meaningful learning (Garrison, 2017). Thus, high social presence goes

hand in hand with an active and balanced participation amongst students without building various cliques in the learning community.

With this in line, Rourke et al. (1999, p. 52) first defined social presence as "the ability of learners to project themselves socially and emotionally in a community of inquiry." Although, adjustments to this original definition have been made over the years. As a broad and incorporating definition, Caskurlu (2018, p. 1) proposes that "social presence focuses on how participants socially interact in online learning environments." Empirical research supports the notion that social presence directly influences the development of cognitive presence (Shea & Bidjerano, 2010; Stenbom, 2018). Consequently, it seems necessary to pay attention to it in the design and facilitation of learning processes. In the case of computer-mediated communication, establishing social presence is particulary challenging because non-verbal communication is absent, and community members are expected to overcome physical distance (Garrison, 2017).

Rourke et al. (1999) selected 12 indicators to measure social presence through quantitative content analysis based on social interaction theories and own teaching experiences. This schema was widely used in the past decades to measure social presence (e.g., Kovanovic et al., 2014; Richardson et al., 2017). Rourke et al. (1999, p. 60) interpret high frequencies of these indicators as "warm and collegial," while low frequencies signify a "cold and impersonal" social environment.

The 12 indicators are grouped into three cateogries: open communication (OC), emotional (affective) expression (AF), and cohesive responses (group cohesion—GC). Open communication refers to "interactive responses" (Rourke et al., 1999, p. 56) in which students refer directly to each other's posts (e.g., by quoting each other's messages or making other references), ask each other questions, and express appreciation for peers or their contributions. Affective expressions help to develop a sense of affiliation with the group, build trust in the community, and thus open up to critical engagement with learning content and peers. Indicators include expressing feelings, using humor, and narratives from personal life outside of class (Rourke et al. 1999, p. 57). The third category includes indicators that refer to group commitment by addressing peers by name, the group as "we, us, our", and by including communication that serves social purposes (e.g., greetings and phatics) (Rourke et al., 1999, p. 59).

Measurement of Social Presence

By now social presence was mostly measured through content analysis and manual coding according to the 12 indicators we introduced in the previous section. The corresponding coding schema was widely used in the past decades to measure social presence (e.g., Kovanovic et al., 2014; Richardson et al., 2017). Additionally, social presence was also measured via self-perceptions of students, through surveys (Arbaugh et al., 2008, Swan et al., 2008). There have been newer attempts to measure social presence via learning analytics in the last few years. Learning analytics aims to gain insights into online learning for stakeholders like students, teachers, or universities by using data available in the learning management system (Knight & Buckingham, 2017). Social presence has, for example, been measured by machine learning prompts (e.g., André et al., 2021; Ferreira et al., 2020) or by automatic analysis of log data (Henrie et al., 2018; Yücel & Usluel, 2016). Overall, the results were promising; however, they were labor-intensive and thus only available retrospectively.

Social Network Analysis

Solving these issues of labor intensive and mainly retrospective data analysis could be done using already available real-time data in the learning management system by measuring social presence through social network analysis.

SNA is a method to gain insights into communities and networks despite traditional statistical methods by describing relationships in networks (Carolan, 2014). It also allows measuring social processes related to learning (Chen & Poquet, 2022; Knight & Buckingham 2017). In learning networks, students represent nodes (actors), and edges represent their relations (for example, interactivity or attributes like knowledge building or final grades).

As a part of learning analytics, SNA was defined early as a key contributor in this field (Siemens, 2013). There have been attempts to measure the social structure of interaction in knowledge-building processes by centrality measures (Shea et al., 2014; Satar & Akcan, 2018), students' influence and prestige in their learning network by degree centrality measures (Wicks et al., 2015), engagement patterns by cohesion and power analysis (Jimoyiannis et al., 2012), and the number of interactions through eigenvector centrality (Saqr et al., 2020).

Already in 2010, Shea et al. stated that "it appears that SNA may be utilized as a tool to automate the measurement of theoretically derived desirable behaviors in online learning environments" (p. 17). First attempts to use SNA to measure social presence showed promising results. Shea et al. (2010) found that density measures could be useful to measure the development of social presence in online learning environments, and Satar and Akcan (2018) tried to show interaction patterns by centrality measures. Ye and Pennisi (2022) found positive correlations between learning performance and degree centrality as well as closeness centrality measures. In a MOOC-investigation Zou et al. (2021) found that social presence indicators of manual coding are highly correlated with SNA measures like degree-, closeness- and betweenness-centrality.

Nevertheless, the overall potential of SNA to measure social presence has not been exploited by now (Jan et al., 2019). It is still unclear which indicators measured by SNA give hints on social presence, and the possible added value of network visualizations was not considered (Jan et al., 2019). In addition, few indicators of SNA have been used as possible measures of social presence. Mainly centrality and cohesive measures have been used (e.g., Kovanovic et al., 2014; Ye & Pennisi, 2022). However, there are still other indicators to be evaluated regarding the measurement of social presence. Based on the available research, there is a lack of statistical evaluation, beyond linear regressions and correlation analyses, that aligns the previous standardized measurement of social presence via quantitative content analysis with indicators from SNA. What is, therefore, still missing is to select and interpret easy-accessible indicators of SNA in a statistically validated and pedagogically guided way to help teachers support learning groups in asynchronous online learning spaces in terms of students' social presence.

Purpose of This Study

To foster social presence in collaborative online learning environments, it is a great advantage when teachers can promptly respond to group dynamics among students. This requires timely awareness and understanding of the ongoing activities within online courses, which can be supported by using concise, validated, and easily accessible measurement tools. An approach for achieving this objective is through the application of social network analysis, a method that has demonstrated promising results in previous research (e.g., Zou et al., 2021;

Papanikolaou et al., 2020; Luo et al., 2019). However, there remains a gap in our understanding regarding which indicators of social network analysis provide insights into social presence defined according the CoIF, how to validate these indicators, and how to interpret these findings in real-time during ongoing courses.

The main research questions in this paper are therefore:

(1) Which indicators from social network analysis can effectively measure social presence in online-based courses, particularly those utilizing the CoIF?
(2) Among the indicators identified from research question (1), which ones demonstrate the highest potential to serve as a measurement tool for social presence in CoIF-based courses?
(3) From the indicators identified in research question (2), which ones are deemed most pedagogically relevant for teachers aiming to enhance the learning experience in CoIF-based courses?

Methods

We chose an online-based graduate master's program as a starting point. We selected three study groups of different sizes, in different study phases, and with different teaching content for our sample.

We exported the available log data from the learning management system. We used them to calculate the SNA for each student (egocentric SNA). Further, to gain a standardized metric for social presence, we exported all students' postings and manually coded these postings using a developed German code book (Kaczkó et al., 2022)

To identify potential indicators from SNA that may predict social presence, we calculated path models for all student groups and at various times of the course duration. Based on this analysis, we further used the non-parametric Friedman test to examine whether a significant change in these indicators over the course duration could be determined.

Grounded in existing research results, we have tried to synthesize which added value these indicators could bring in the context of the CoIF. Additionally, we tried to analyze what useful information teachers could draw from it to possibly improve the instructional design and learning process with respect to social presence.

Sample

Data was gained from the postgraduate online-based master's program "Health Information Management," which was developed based on the pedagogical implications of the CoIF (Ammenwerth et al., 2017). The "RCSEQ: Research Committee for Scientific Ethical Questions" (Ethics Committee) thoroughly examined and approved the study proposal before its implementation (#2877/21). This master's program has a duration of 5 semesters, divided into 15 modules, with in total of 90 credits. The modules in the online courses have a duration of 6 weeks and consist of weekly learning materials, regular (primarily written) course assignments, and ongoing mandatory discussion prompts. While weeks 1 through 5 mostly consist of sequential asynchronous instructional tasks that students are expected to review and discuss together, week six mostly consists of final exam assignments or final

discussions with teachers and project submissions. The course assignments first invite all students to post in their own discussion thread, and then students are encouraged to engage in dialogue with each other in the various discussion threads.

Three different modules from three different student groups were chosen for this study. By doing so, we were able to include different student groups with different group dynamics and personal characteristics in our study as these may influence social presence. Chosen modules also came from various semesters in the program (semesters 1, 3, and 4), allowing us to cover student groups at different level of group formation processes that may be reflected in different level of social presence within the group. The modules took place 2018–2020, before the global pandemic, so we do not have global health and social issues as possible bias. We exported all 3,546 postings from all 49 students in these three modules from the learning management system and pseudonymized them. A detailed description of the sample sizes, the number of postings, and Module contents can be seen in Table 1. Teacher postings were not included as in the used coding scheme, no indicator for social presence is based on teacher postings (Rourke et al., 1999). In addition, only messages written as part of instructional tasks were considered, as this content is relevant and can be measured for social presence in ongoing courses. Threads such as questions about the course were therefore not considered, as we wanted to determine in our study in which areas relevant to learning content social presence could possibly be measured by SNA. The evaluation of the calculations was done on a weekly basis for the instructional tasks in all five weeks. Week 6 was excluded because this is where students mostly have final discussions with the teachers, upload project assignments, or write exams online, and there are no/barely any asynchronous discussions anymore. This was done mainly to account for the progressive development of social presence (Garrison, 2017) and to make the actual measurability ascertainable by means of the indicators of the SNA. Instructional tasks were summarized on a weekly basis and used for further analyses.

Table 1

Modules Selected for Analysis (Health Information Management Master Program).

Module	Topic	Year	Semester	Students	Total Postings	Postings in Instructional Tasks	Content
1	Professional project management	2020	1	22	1,476	1,256	project management
2	Clinical classification systems and semantic interoperability	2018	3	12	923	882	clinical documentation
3	Software quality engineering	2019/2020	4	15	1,147	935	basic concepts/ and

				software development processes
Total	**49**	**3,546**	**3,073**	

Note. Participating students were different in all modules.

Manual coding

Manual coding of students' postings was supported by MAXQDA 2020 (VERBI Software, 2019). For this purpose, the pseudonymized postings of the students were imported into the software. Based on the already existing coding schema of the original authors (Rourke et al., 1999), a German code book was developed (for a detailed description of the German code book please see Kaczkó et al., 2022).

Each posting was carefully read for manual coding, and one or more indicators were assigned. Coding was done for the three categories of Social Presence: Affective Expression (Indicators AF1-AF3), Open Communication (Indicators OC2-OC6), and Group Cohesion (Indicators GC1-GC3) based on the original coding schema. Indicator OC1 "Continuing a thread" was omitted, as students used the reply function in the learning management system continuously, as done by others (e.g., Kovanovic et al., 2014).

To validate the coding schema and do a trial of data export, one Module (Module 3) was coded by two research group members. Half of the postings in this Module, 650 posts, were coded individually and later discussed to reach a consensus. A third expert in the research group was consulted in case of discrepancies. The remaining 497 postings were coded independently, where overall, a consensus of .81 (Cohen's Kappa, κ; calculated on the level of 11 indicators) could be achieved. Two trained coders within the research group coded the two other Modules (Module 1 and Module 2). Initially, 100 postings were coded together, and then the coders coded 500 postings individually, where discrepancies were discussed in the research group afterwards. Finally, the remaining 876 (Module 1) and 323 (Module 2) postings were coded independently. Here an agreement (Cohen's Kappa, κ) of .93 for Module 1 and .89 for Module 2 (calculated on the level of 11 indicators) was achieved.

Following the manual quantitative coding, the score in each of the three social presence categories was calculated for each student on a weekly basis. For example, if a student wrote 20 postings in week one, of which five postings were coded with indicators of Affective Expression, a value of 25% was calculated for this student in the category Affective Expression in week one. These values were calculated for all three categories of social presence for all 49 students in the sample for each of the five weeks in their 6-week course duration and used for further statistical analysis.

Social Network Analysis

We exported the available log data from the learning management system and used them to calculate the social network indicators. We used the students in the three groups as actors (S1–S49, N = 49) and the messages written as relations (ties) between these students. The software UCINET was used to calculate the SNA and the indicators, and Netdraw was used for visualization (Borgatti et al., 2020).

We conducted the SNA based on egocentric social network measures. Thus, each message written from one student to another (addressed by name or reply function; parent-child) was a direct link between these students. Messages from teachers were not included.

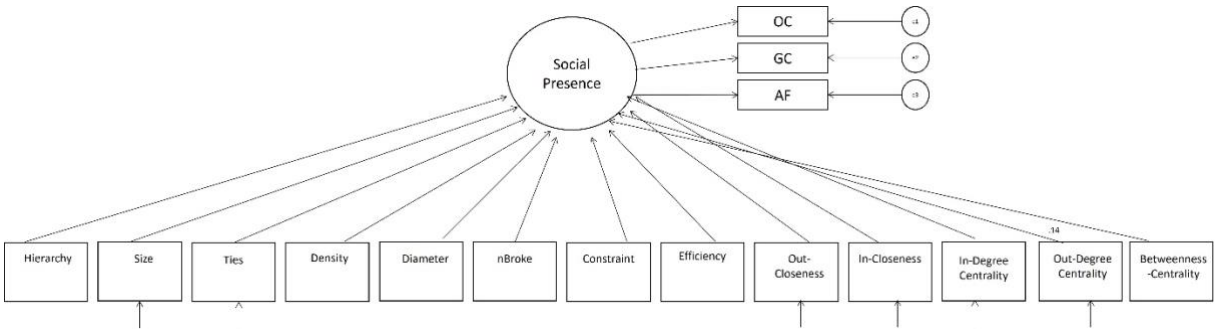
In the first step, we included all indicators of SNA, which are computable on egocentric levels with the available data in the learning management system, to statistically analyze which of these indicators could serve as possible metrics for social presence. The overall used indicators, calculation methods, and pedagogical implications found in previous studies concerning social presence are presented in Appendix A. In a second step, these indicators were differentiated and sorted based on existing literature and identified implications.

Path Analysis

After manual coding and the social network indicators had been calculated, we calculated path models for each week of course duration in the three student groups. We did this to evaluate whether the significant indicators and their standardized regression weights changed over weeks and/or remained constant significant indicators over the course duration. Our path model was based on the theoretical grounding of the different indicators and their influence on social presence, primarily based on earlier research findings. Based on this a priori set theoretical grounding, we considered some of the indicators to interact with each other intensely. For example, an underlying assumption of interaction is seen between the postings written (Out-Closeness) and the postings received (In-Closeness). Also, the number of ties strongly interacts with the number of actors in the model. Due to this assumption of multicollinearity, no regression analysis was performed, as an interpretation of these results would not have been reliable. The path models do take account of these interactions. Our theoretical model for path analysis can be seen in Figure 1.

Figure 1

Path Model Based on Theoretical Grounding With Respect to Multicollinear Interactions Between Indicators



The dependent variable in our model was social presence, defined by the findings of the quantitative manual coding. The 13 indicators from egocentric network analysis were our independent variables. Both data came from the respective week, so there were five path models for each study group and an overall path model for the whole course duration. We used AMOS (Arbuckle, 2014) and R (R Core Team, 2014) for visualization and calculation.

Progression of Indicators Over the Course Duration

After evaluating the indicators using the path model of each week, we examined the extent to which a progression of the indicators could statistically be determined over the course duration. The reason is our assumption that social presence changes during the five weeks with respect to our course design (see Sample). To statistically detect changes we used the non-parametric Friedman test for dependent samples for all indicators across the five weeks course duration for each study group. The calculation was done using SPSS (IBM Corp., 2020).

With the non-parametric Friedman test for dependent samples, it is possible to analyze whether the central tendencies of several dependent samples (in our case, the weeks 1–5 in the three student groups) differ. Dependent samples in our study, are due to the measured values (egocentric social network indicators) origin from the same persons over the measurements (five weeks). This test is used when the requirements for analysis of variance are not given, which is true in our case.

First, we examined for each indicator separately whether a significant difference could be found in the respective study groups over the five weeks and how these changes develop over the course duration. The resulting p-values were corrected using Bonferroni correction procedure.

Interpretation and Analysis of Social Network Indicators Based on Existing Literature

As SNA was already used as a measurement tool for social presence in some exploratory studies (e.g., Ye & Pennisi, 2022; Ferreira et al., 2020; Shea et al., 2010), we tried to evaluate and merge the already existing findings in this area.

Based on a systematic literature review conducted by Jan et al. (2019), we sought additional studies that focused exclusively on social presence in the context of CoIF and SNA. Next, we categorized the SNA indicators that serve as measures of social presence (based on the path models and the non-parametric Friedman Test), and aligned them with existing results.

Furthermore, we have tried to summarize the pedagogical implications reported by others and centre them on the possible use of the indicators. In addition, we consolidated the results on the progression of social presence already found in SNA over course durations to our findings and the impact of this development on learning and teaching in online courses.

Results

We will now systematically present our findings aligned with our three research questions:

Chapter 3.1 provides descriptive statistics for manual coding of social presence in the three respective cateogries: Open Communication, Affective Expression, and Group Cohesion.

Chapter 3.2 shows the results of the SNA in the three modules on the entire network level to gain an overview of the used indicators over course duration.

Chapter 3.3 presents the results of the path analyses over the five weeks of course duration, identifying indicators as possible metrics for social presence (research question 1).

Chapter 3.4 identifies that these indicators progress and are trackable over the course duration (research question 2).

Chapter 3.5 elevates present research findings in light of social presence and used indicators of SNA (research question 3).

Chapter 3.6 finally shows the progression of the identified indicators (research question 3) and merges the findings from literature analysis and pedagogical considerations.

Frequency of Social Presence Categories

Manual coding was done for all student postings in all three modules using the developed German codebook. Coding was done based on the indicators for each social presence category. Finally, each indicator was summarized in the present category, and an overall degree for each student was calculated based on these codings.

Appendix B presents overall coding frequencies (relative and absoulte) for each student group and the five weeks of course duration in all three modules and for all three categories of social presence.

Appendix C presents the individual codings of each students posting on weekly basis over the five weeks of course duration for all three modules.

The results show that the distribution of the three categories of social presence is comparable in all three modules, although the number of postings and size of student groups varied. Nearly all modules show 50% of the frequency of Open Communication category almost constant in all course weeks whereas Group Cohesion category shows the least distribution, between 6 and 17% (Appendix B). It should be mentioned that Open Communication is measured by five indicators while affective expression and group cohesion each by three, which might distort the result. Affective Expression indicators are about one-third of all indicators, although they vary between weeks and student groups.

Comparing the three modules to each other, we perceive some differences in the evolving of social presence, as depicted in Figure E1 (Appendix E). Module 1 starts with a relatively low social presence in comparison to the other modules, and a slight continuous decrease is noticeable in the following weeks. This might be explained by the fact that this module is one of the first modules of the master's program, and the students are new in the learning group. Module 2 starts with a relatively high social presence in comparison to the other two modules, and a slight continuous decrease is noticeable in the following weeks. Module 3 starts with the lowest social presence (in relation to the group size). However, we notice higher frequencies in week two, which remain stable during the following weeks.

Social Network Analysis

Based on the student postings (parent-child), SNA was conducted for all three student groups over the assigned weeks. An overview of all thirteen SNA indicators used as a starting point for all analyses can be found in Appendix A, along with descriptions of the individual indicators and their significance.

Appendix D shows the detailed network data.

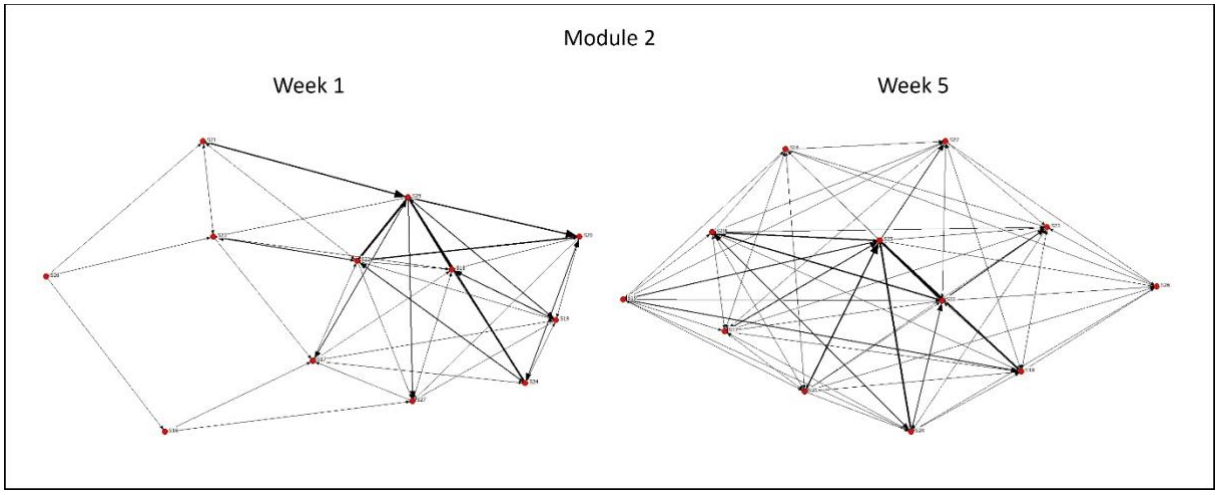
The network of Module 1 consisted of 22 nodes representing the students. At the end of week one, 81 ties (connections between students) evolved, whereas at the end of week five 202 ties evolved. The network got dense over the course duration (density week one: 0.175; week five: 0.435), and the diameter (longest path in the network) decreased from 5 to 3. All students communicated in one component, without any subgroups.

The network of Module 2 consisted of 12 nodes, representing the students. At the end of week one, 56 ties existed, while at the end of week five, 100 ties were formed. The network graph for Module 2 can be seen in Figure 2 for week one and at the end of the module. As also seen in Figure 2 density of the network evolved over the five weeks from 0.424 to 0.758, which indicates that the network is very dense. The Diameter in the network decreased from 3 to 2. In week one, the network consisted of three components, whereas at the end of the Module, the network evolved into one component. No subgroups existed over the whole course duration of Module 2.

The network of Module 3 consisted of 15 nodes, representing the students. At the end of week one, only 39 ties were created. The network scaled up to 108 ties at the end of week five and got denser over the weeks (0.186 to 0.514). Diameter diminished from 6 in week one to 3 in week five. In week 1, two components existed in the network, without subgroups, and evolved to one component at the end of week 5.

Figure 2

Overall Network Graph for Module 2 at the End of Week 1 and at the End of Week 5



Note. Nodes represent students, edges represent students' posts, and graphs are weighted and directed.

Potential Indicators for Social Presence Via Path Analysis

Path analysis was done to prove which indicators from SNA may serve as an appropriate metric for social presence in the course weeks. Path analysis thus answer research question 1: *Which indicators from social network analysis can effectively measure social presence in online-based courses, particularly those utilizing the CoIF?*

Therefore, five path models for each week were calculated. The standardized regression weights were used for analysis and can be seen in Table 3 for all used indicators. The model fit was not taken into account, as we cannot consider the path model to be outright, and it is nearly impossible to consider all factors that work as independent variables in the case of social presence in online learning environments.

As seen in Table 3, considering the overall course duration, six indicators showed significant findings and relatively high regression weights. The most appropriate indicators

that could serve as metrics for social presence with the highest regression weights over all five weeks are Density (path coefficient = .570, $p < .001$) and nBroke (path coefficient = .474, $p < .001$). Four more indicators show moderate regression weights over all weeks, namely Constraint (path coefficient = -.298, $p < .001$), Out-Degree-Centrality (path coefficient = .207, $p < .001$), Betweenness Centrality (path coefficient = .220, $p < .001$), and Hierarchy (path coefficient = .216, $p < .001$).

The findings are slightly different in the more detailed analysis for the single weeks, seen in Table 3. One indicator is suitable to measure social presence over all five weeks, namely nBroke, with high regression weights over all weeks. Other indicators, such as Ties and Density, are valued measurements for social presence, but not across all weeks. Variations in regression weights weekly are also evident. Some indicators, such as nBroke and Efficiency, show alternating negative and positive standardized regression weights over the course duration. These indicate different circumstances in the course and could be related to instructional tasks. These findings are further discussed using a show case of a real course example in Appendix E.

In summary, as depicted in Table 3, not all indicators consistently demonstrate significant standardized regression weights across all weeks. For further analysis, we included those indicators that showed at least a significant result in the path analyses and were not excluded based on pedagogical implications beforehand (see Appendix A). These indicators were: Ties, Density, nBroke, Constraint, Out-Closeness, In-Closeness, In-Degree Centrality, Out-Degree Centrality, Betweenness Centrality, Hierarchy, and Efficiency.

Table 3

Standardized Regression Weights From Path Analysis for the Five Weeks Course Duration

Indicator	Standardized Regression Weights					
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Overall**
Size	.132	-.224	-.233**	-.164**	.589**	-.403
Ties	-.531	.229	.242**	.087	-.438**	.025
Density	-.067	.639**	-.655**	.737**	-.304**	.570**
Diameter	-.004	.017	.022	.022	.093	.062
nBroke	-.443**	.654**	-.724**	.643**	-.546**	.474**
Constraint	.262	.010	-.008	-.077**	.080	-.298**
Out-Closeness	.083	.019	.035	.078	.119**	.157
In-Closeness	-.005	-.254*	-.075	-.072	.002	-.152
In-Degree Centrality	.419**	.203**	.003	-.020	-.118	.166
Out-Degree Centrality	.290	.102	.039	.015	.097	.207**
Betweenness Centrality	.014	.109	.091**	.078**	.042	.220**
Hierarchy	-.211	-.023	.003	.087**	.119	.216**
Efficiency	.342**	-.026	.116**	.108**	.045	-.070

Note. Numbers represent standardized coefficients. ** ($p < .001$)

Progression of Indicators Over the Course Duration

After the analysis of the findings of the path models, we inspected the possible indicators for social presence from SNA in more detail. We wanted to know how the indicators evolve over time (during the course duration) in the different weeks of the course duration to answer research question 2: *Among the indicators identified from research*

question (1), which ones demonstrate the highest potential to serve as measurement tool for social presence in CoIF-based courses?

The results of the non-parametric Friedman test over the five weeks for each student group separately for each indicator of SNA, showed valuable results in the path analysis (Appendix F). Overall, it was possible to see changes of the progression of indicators in all three modules over the five weeks. The following indicators did not show these changes: Constraint, In-Degree Centrality, Hierarchy, Betweenness Centrality, and Out-Dregree Centrality ($p > .005$); we, therefore, did not take these into account for further analyses. The indicators Ties, Density, Out-Closeness, and In-Closeness showed significant increase, whereas the indicators nBroke and Efficiency showed significant decrease. These six indicators and their progression were thus investigated further in the next step.

Selection of Pedagogical Meaningful Indicators

Complementary to the statistical analysis, classification based on existing literature was done to answer research question 3: *From the indicators identified in research question (2), which ones are deemed most pedagogically relevant for teachers aiming to enhance the learning experience in CoIF-based courses?*

Based on the literature research and theoretical considerations of the CoIF, we selected suitable indicators. Our goal was to find indicators for social presence from SNA, which are both: statistically unambiguous and pedagogically meaningful. In doing so, we exclusively considered indicators that play a role in SNA but have never been considered in connection with social presence, as well as indicators that have already been used successfully in this latter. Appendix A presents this analysis in more detail.

As a first step, we selected indicators from SNA that had already been used in preliminary studies in CoIF research, as well as indicators that have never been considered in this field before (Appendix A). In the next step, we removed the indicators that showed no relevance in the first statistical analysis (the path models) or were not informative for teaching in CoIF-based courses. We, therefore, removed the two indicators, Size and Diameter. Further, we removed the indicators that showed no traceable progression in the modules and the statistical analysis of the development of the indicators (Friedman test). The five indicators deleted are Constraint, Out-Degree Centrality, Betweenness Centrality, In-Degree Centrality, and Hierarchy.

Based on the systematic literature review conducted by Jan et al. (2019), we did an additional literature search for 201–2022. Jan et al. (2019) synthesized nine studies that exclusively deal with social presence in the CoIF and SNA as a measurement of the latter. These studies were conducted until 2018, where no lower limit of publication was set. Eight of these studies use asynchronous online discussions in higher education as data material. We found six additional studies in the years 2018–2022 and one study already conducted in 2014, which was not included in the literature review of Jan et al. (2019). In total, we used 15 studies conducted between 2010–2023 to analyze the indicators of SNA. In Appendix A, we summarized the description and meaning of these indicators and assigned the studies with their key findings and pedagogical implications.

The indicators Density, Out-Closeness, In-Closeness, In-Degree Centrality, Out-Degree Centrality, and Betweenness Centrality were investigated by various authors (cf. Appendix A). In total, seven studies have used the indicator Density for analyzing social presence, participation rate, interactivity, and activity rate. The indicators Out- and In-

Closeness were used in three different studies each, mostly as indicator of social presence or interactivity. Indicators of Centrality measures (In-Degree Centrality, Out-Degree Centrality and Betweenness Centrality) were used in 11 studies (In-Degree), 7 studies (Out-Degree), and 3 (Betweenness) studies. These indicators were mostly used as indicators of prestige, influence or interactivity. Other indicators such as Hierarchy, Size, Diameter or Constraint were only used in one study. The indicators nBroke and Efficiency were not used in any study found.

To summarize, in our literature analysis we have identified studies that endeavor to integrate indicators from both SNA and social presence. Notably our investigation reveals a noticeable gap in the existing research, as no prior study has systematically employed SNA indicators as a direct metric for social presence and validate this attempt. Furthermore, the synthesis of pedagogical implications often diverges from the theoretical framework of the CoIF and indicators were sometimes equated with different terms such as interactivity, interaction or social presence. Based on the results presented here, interpretations and guidelines for action for our indicators will now be derived.

Using the Selected Indciators to Identify Progression of Social Presence

In conclusion, we finally want to adress the third research question based on the presented results, namely, "*Which indicators are deemed most pedagogically relevant for teachers aiming to enhance the learning experience in CoIF-based courses?"* and illustrate how these indicators could be used tracking the progression of social presence over course duration.

In Figure 3 we show an overview of the progression of the indicators, which are explained in more detail below over the five-week course duration.

Considering the progression of social presence in terms of social network indicators, we first looked at the indicator Ties. As a starting point in online courses, observing how multiple connections (.also known as Ties) form between students to see how social presence develops could be helpful. It should be the starting point and the first control in ongoing courses to see the interactivity increase in a course. The progression of the indicator Ties can be seen in Figure 4 in all three modules. In all modules, we see smaller numbers of ties built in the first weeks (Module 1: 7 ties, Module 2: 20 ties, Module 3: 3 ties), whereas these numbers increase significantly over the course duration and peak at the end of the course (Module 1: 86 ties, Module 2: 64 ties, Module 3: 48 ties). In Module 1, this increase in ties occurs most clearly. This perhaps implies that students who are new to a learning group, as in Module 1, engage more actively in relationship building than this is the case in established learning groups.

As a next step in analyzing the progression of social presence through indicators of SNA, we take a closer look at Cohesive metrics and metrics related to special network positions. Density, Out-Closeness, and In-Closeness increase significantly over the weeks, whereas the indicators nBroke and Efficiency decrease in our three Modules. Accordingly, the values of the individual students reveal that the network consists of more connections, it becomes denser, and the students establish more contact with each other over the course duration. Furthermore, the course of brokerage positions, which naturally exist at the beginning of courses when not all students are in exchange with each other, decreases significantly over the course duration. This indicates that a community is formed, at least by means of the participation of all students, to a similar extent. Regarding the CoIF, a

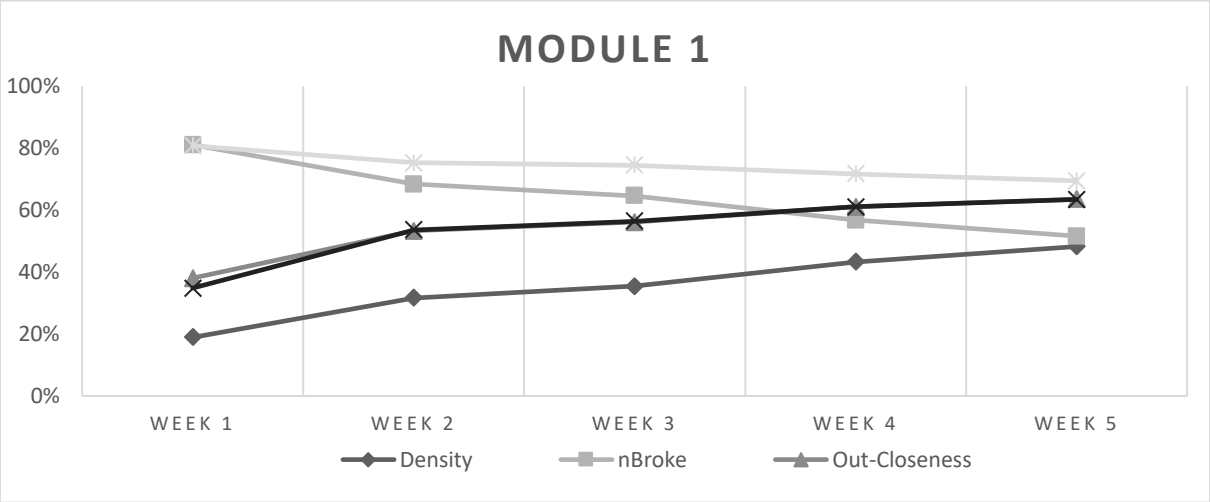
community is formed where equal critical exchange can occur (Garrison, 2017), and we consider full participation as a prerequisite.

To outline the brokerage positions and the importance of information flow and network positions in general, we will explain the concept of Efficiency in more detail. By Efficiency, in our case in egocentric network is dealing with information flow in the neighborhood of a student. In learning networks, special positions regarding informational flow are somewhat hindering, as all students need the same information to enter a meaningful discussion. In terms of a community of inquiry, it is therefore essential that students are connected with each other and that interactivity in respectively social presence, is high.

We attached a showcase based on Module 1 in Appendix E to make our results and the associated possible implications understandable. Here we show in more detail which results from the individual indicators were gained, based on which tasks these can be explained, and further in the discussion section, we will explain which benefits teachers could possibly draw from this in the future.

Figure 3

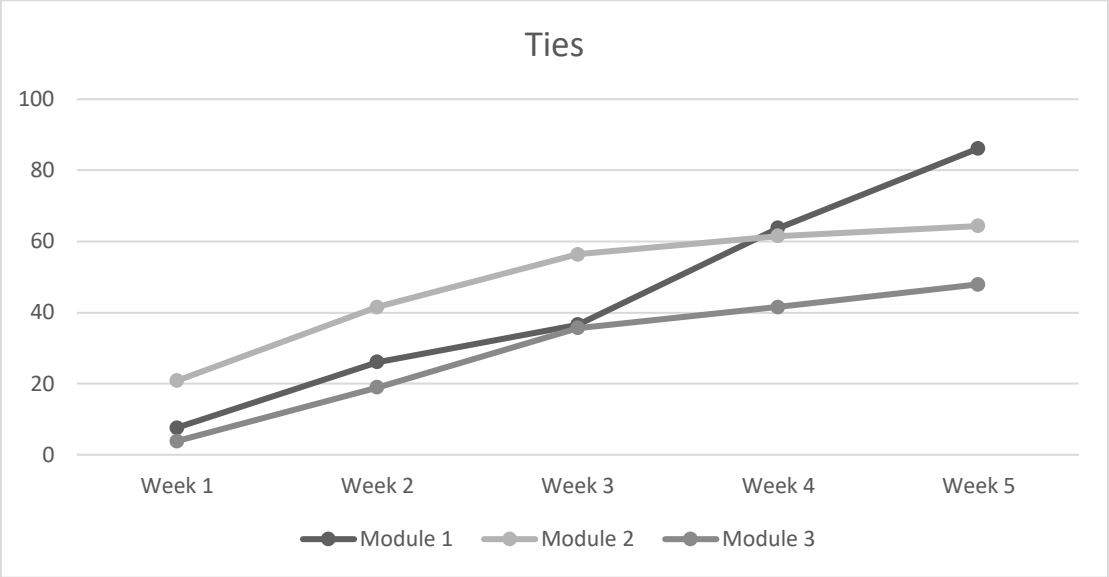
Development of SNA Indicators (Density, nBroke, Out-Closeness, In-Closeness, Efficiency) Over the Five Weeks Course Duration in Module 1 in Percentage



Note. For a definition and discussion of pedagogical relevance of each indicator see Appendix A.

Figure 4

Development of SNA Indicator Ties Over the Five Weeks in the Modules 1–3 in Relational Numbers



Discussion

At the beginning of our discussion, we summarize the results of our complex research process and place them in the context of existing research results from previous work. We then address the pedagogical implications arising from our research and delve into the assessment of the progression of the indicators (and thus social presence) and their implications for instructional practice in ongoing courses. Finally, we discuss possible limitations and the need for further research based on our findings.

Statistical Findings of Identyfing Indicators as a Possible Measure of Social Presence

As a starting point, we considered 13 indicators of SNA that could serve as possible metrics for social presence. Through theoretical considerations based on the CoIF, as well as through path analysis in which we contrasted social presence, measured by manual quantitative coding, as the dependent variable and the indicators of the SNA, we were able to identify 11 indicators across the five weeks that could serve as metric for social presence. We then examined whether these indicators changed significantly over the course duration in weekly instructional tasks and, thus, whether indications of the course events regarding social presence could be determined.

Based on our research question, which indicators of SNA are suitable to measure social presence in real-time during ongoing online courses, we were finally able to identify six indicators that show great potential to measure social presence in ongoing courses. The indicators Ties, Density, In-Closeness, Out-Closeness, nBroke and Efficiency are easily calculated with already available data in the learning management system, and their progression over the course duration can be determined. Not only are these indicators statistically significant indicators for social presence, but they are also valued by pedagogical considerations. Regarding the latter, they show the development of a learning group where all participate and no cliques evolve. This is a prerequisite to forming a community of inquiry

that critically discusses and reflects on given topics. These results are consistent with the findings through the manual coding, which already showed a high frequency of social presence measures and, thus, a warm and collegial social environment.

The indicators with the most significant and highest standardized regressions weights in path analysis were Density and nBroke. Both showed standardized regressions weights over .70, whereas nBroke showed highly significant regression weights over all weeks, and Density in all weeks, except week one. As week one is the "starting point" of all social happenings in our Modules, the networks are not fully built yet, and it may therefore be that Density is still low. NBroke has not yet been considered a potential social presence metric in previous research. In contrast, in previous studies, Density has been shown as a possible indicator of social presence.

The indicators In- and Out-Closeness each showed significant standardized regression weights in only one week (In-Closeness in week two, Out-Closeness in week five), and both were rather small. Nevertheless, these indicators were used for further analysis. In- and Out-Closeness are, from a pedagogical point of view, foundations for the emergence, maintenance, and promotion of social presence. The exchange between students is a basic requirement of a Community of Inquiry (Garrison et al., 2001), and both indicators provide valuable information about this exchange. Both indicators have been explored in previous research as metrics of interactivity, social presence or learning performance (e.g., Ye & Pennisi, 2022; Zou et al., 2021; Papanikolaou et al., 2020).

The indicator Ties showed significant standardized regression weights in weeks three and five, while the indicator Efficiency showed significant standardized regression weights in weeks one, three and four. Based on these results, both indicators were included in the further analyses. These indicators have, to our knowledge, never been considered as possible metrics for social presence.

To answer research questions (1) and (2)—"Which indicators from social network analysis can effectively measure social presence in online-based courses?" and "Among the indicators identified from research question (1) , which ones demonstrate the highest potential to serve as a measurement tool for social presence in CoIF-based courses?"—we can state that from a statistical point of view our six indicators Density, nBroke, In- Out-Closeness, Ties and Efficiency are suitable indicators. All these indicators showed highly significant findings in the non-parametric Friedman test and the development of all six indicators was trackable.

Implications of Literature Analysis for Possible Indicators of Social Presence

In our literature review, we have provided some examples of the use of indicators of SNA and social presence, as well as different terminology for different indicators. In the following, we will now take a closer look at these results.

Regarding the three measures (Density, Out-Closeness, In-Closeness), the authors either refer to social presence in general terms (which is measured by these indicators), or they put it right along with terms such as participation, activity or interactivity, which might indicate that the findings are not so much connected to the theoretical foundations of social presence according to the CoIF. The studies derive highly deviating pedagogical implications (which might be a loose selection from existing literature), such as the instructors' and assignments' role in developing social presence, students' active involvement in learning, forum participation for the prediction of retention, social award approach to empower communities, encouraging students to connect and to express themselves.

Looking at Degree-Centrality measures, some authors refer to social presence in general terms and interactivity to be measured. Furthermore, some other authors discussed the

influence of the students within the learning group. For instance, In-Degree Centrality might show how successful students are by triggering others (Jimoyiannis et al., 2012), and Out-Degree centrality might show how students engage more in discussion (Wicks et al., 2015) and influence others through their interactive behavior (Lou et al., 2019; Shea et al., 2014). However, based on the theoretical foundations of CoIF, influential students would be less the focus of interest and much more full participation in the community of inquiry and how it can be supported on the group level (cf. Social Presence as Part of the Community of Inquiry Framework).

Surprisingly, the indicators Ties, nBroke and Efficiency have not yet been considered as indicators for the measurement regarding the CoIF but could deliver important values and give hints about special or brokerage positions in the network and thus about full or partial participation within the learning group.

Pedagogical Implications and Possible Interpretations of the Indicators Found

A first step in assessing social presence in ongoing courses and initial indications of potential barriers to social interactivity in courses are readily available and highly informative via the SNA indicator Ties. If students do not connect, no community can emerge, and indeed, not a community of inquiry where a critical exchange is possible (see Akyol & Garrison, 2008; Garrison, 2017).

As the course progresses, it is important to observe whether the networks that form in the course become denser. The degree of interactions gives valuable hints of social presence in ongoing courses (Jan & Vlachopoulos, 2019), where the Density indicates to what extent students are connected to each other and how many connections they have from all possible connections. This allows us to estimate on which continuum the learning group is, from casual to full participation.

Furthermore, it is helpful to see if “special” network positions settle moderately over the course. A network is more stable the more reciprocal it is and the shorter the distances between actors (Borgatti & Halgin, 2011), which in our case for learning communities, means a short path of information flow and exchange between students. Brokerage positions could be helpful in specific networks, like in the theory for social capital, it could be helpful for the acquaintance of new information like job offers (Borgatti & Halgin, 2011). This is not true for a community of inquiry, which should at least be based on mutual exchange and information flow (Short et al., 1976). Students engaged in online learning environments per se show higher degrees of transactional distance in comparison with students in face-to-face settings (So & Brush, 2008), so it could be a necessary prerequisite of learning networks to decrease this distance, as well as in students' perception as in the network indicators Efficiency and nBroke.

Finally, there can be no community and certainly no community of inquiry without interactivity. For this, it is necessary to see whether students get in contact with others (Out-Closeness). Previous work showed that learners should express themselves to boost their network status (Zou et al., 2021). There could also be students with other posting behavior, like silent readers (Wang et al., 2015), that ideally get motivated by teachers or peers to participate in the course actively. The students' incoming messages might also be considered. Our results have shown that these indicators go hand in hand. It is, of course, highly beneficial in terms of a learning community if mutual exchange happens. Nevertheless, this is probably not the rule, and there are always outliers, such as super posters (Huang et al., 2014). A balance of in-coming and out-going messages would be optimal for students in terms of a community of inquiry.

To answer the research question (3)—"Which ones are deemed most pedagogically relevant for instructors aiming to enhance the learning experience in CoIF-based courses?"—we can state that according to our literature analysis as well as further pedagogical considerations and our show case, the six indicators Ties, Density, In- and Out-Closeness, nBroke and Efficiency are suitable for this purpose.

Closing this section, we might mention some literature which collects various recommendations on how social presence can be enhanced in CoIF-based courses. Fiock (2020) systematically collected instructional strategies from past literature, amongst others, to support social presence. There are further useful recommendations in some previous literature, such as guidelines for practice by Garrison (2017, Chapter 9) and Richardson et al. (2012).

Classification of Our research in Existing Results

So far, social presence has mostly been measured restrospectively and labor-intensively by manual coding (cf. Richardson et al., 2017; Rourke et al., 1999) or by newer approaches via learning analytics (cf. Ferreira et al., 2020; Ruthotto et al., 2020).

By measuring via our identified indicators, it could be possible to measure social presence in real time in courses currently taking place via existing data from the learning management system. To date, the indicators used in the analysis of social networks have neither hardly been linked to theoretical underpinnings (Lou et al., 2019; Wicks et al., 2015), which we have attempted to do through our literature review. Nor were possible links with social presence statistically sufficiently considered and confirmed (cf. Dado & Bodemer, 2017), which we tried to address through our statistical analysis.

As learner engagement decreases in distance learning environments (Dumford & Miller, 2018), our indicators could be a starting point to work on this. By improving social presence in learning environments based on the CoIF, the overall educational experience could be improved. Teachers could be able to provide adequate feedback, adjust course design when necessary or promote social components. To do this, teachers need timely information that is easy to understand, accessible and pedagogically relevant.

Limitations and Further Research

Although the statistical analysis was very extensive and considered several specific viewpoints that have emerged as problematic in preliminary work, such as not considering multicollinearities or looking at the progression of indicators, some limitations should be discussed here. First, we did not consider the individual instructional tasks in the modules in isolation but summed up both the results of the manual quantitative coding and the calculations of the indicators from the SNA across the tasks. We did this because social presence, by definition, is considered progressive and evolving (Garrison, 2017). However, the ties between students in week one are also relevant to students' social presence in week five. Looking at individual instructional tasks in isolation could yield different results.

Furthermore, we used only the postings from the instructional tasks for our calculations, as these are relevant for grading students. Whether and to what extent the social presence has changed by, for example, asking questions in the general course area or by further contact among students outside the learning management system, we cannot determine with this. We are unaware of further face-to-face or online contact between students beyond the learning management system.

In terms of good practice ethics in the context of learning analytics (Prinsloo et al., 2017), we also do not want to establish a control instance for communication between students but rather to achieve an improved educational experience for instructors and students. Instead, through the available indicators, we want teachers to react adequately to interactions and group formation events without giving students the feeling they are being monitored and by bringing social presence in courses to an optimal level.

Additionally, it remains to be noted that the sample used here comes from a master's course built on the theoretical foundations of the CoIF and therefore builds in many basic tenets toward high social presence. Furthermore, our course design allows and requires many interactions between students. For example, in the instructional tasks, students are explicitly asked to respond to each other's posts or to ensure that each student receives a response, which is part of the grading system. Our findings might not be relevant for courses that are designed according to other theoretical frameworks and models or where little is done to promote social presence.

Further research should now test these indicators in practice. It might be investigated to what extent the use of these indicators can be helpful for teachers (or even students) in ongoing courses to assess the progression of social presence and to intervene when necessary.

Additionally, further studies might examine the development of social presence in courses for the same cohort of students. Although social presence is a relatively well-established construct, no study examines in detail how social presence develops over the course duration.

Conclusion

We found six indicators that show great potential to serve as metrics for social presence in real-time in ongoing CoIF-based courses. These indicators are based on easily accessible data available in the learning management system. These systematically selected indicators are not only statistically meaningful for social presence but they are also valued by pedagogical considerations. Together, they can show the progression of a learning group regarding incomplete to full participation over a course which is vital to form a community of inquiry that critically discuss and reflect on given topics. These results are consistent with the findings through the manual coding that grounds the statistical analyses. Further research should now test and validate these indicators in the field in different settings. These indicators could enhance teachers to improve their online learning with timely feedback, course adaption or enforcement of social components, which could lead to a meaningful educational experience.

Declarations
The authors declare no conflicts of interest associated with the research in this article.

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Appendix A

Selected SNA Indicators as Possible Measurement for Social Presence

NAME	DESCRIPTION & MEASURMENT OF INDICATOR	MEANING OF INDICATOR IN ONLINE COURSES	KEY FINDINGS	PEDADAGOGICAL IMPLICATIONS	REFERENCES
Ties	Number of connections between ego and his alters (Relational Data)—Number of Ties present	How many ties are there between students? Number of students with whom student xy is connected in this Module (direct exchange)			
Density	The extent to which ego is connected to his alters Number of ties present/Total number of potential ties	How intensively are students connected to each other? How many connections does student xy have in this Module with his fellow students from all possible connections?	Indicator of social presence Indicator of participation rate Indicator for activity rate Indicator of social presence Indicator of interactivity	Importance of instructor contributions for development of social presence The discussion forum is the social space to form group identity. Forum participation is useful to predict retention; strong group performance promotes cognitive processes. Unclear (qualitative investigations needed)	Shea & Bidjerano (2010) Tirado et al. (2015) Jo et al. (2017) Satar & Akcan (2018)

			Indicator of social presence	Dense students are actively involved in exploratory learning	Luo et al. (2019)
			Indicator of social presence	Open and creative tasks promote communication toward task objective as well as responding to suggestions from peers	Tirado-Morueta et al. (2019)
				When students actively participate there are more opportunities to connect.	Norz et al. (2023)
Efficiency	The effective size of alters in ego's network Alters in ego's' network (number of alters)	How many other students are in student xy's network (in regard with information flow)? If student xy is deleted from the network how will information exchange, go further.			
NBroke	The extent to which ego is located “between” two alters (Brokerage Position) Sum how often ego lies on directed path between two actors	How often is student xy on the connecting path between other students? How often does student xy form the bridge between 2 students?			

Out-Closeness	Outgoing average distance from ego to all other actors in network Inverse of the sum of the geodesic distances between actor I and the g-1 actors in the network	How "far" is student xy from the other students in the Module? How many out-going messages does student xy send? How well does student xy integrate into the group?	Indicator of interactivity Indicator of social presence Indicator of social presence	Easier to obtain learning resources and knowledge transfer from others Social award approach as a way of empowering communities works. Learners should engage in expressing themselves to boost their network status.	Luo et al. (2019) Papanikolaou et al. (2020) Zou et al. (2021)
In-Closeness	In-Coming average distance from ego to all other actors in the network The inverse of the sum of the geodesic distances between actor I and the g-1 actors in the network	How "far" is student xy from the other students in the Module? How many in-coming messages does student xy receive?	Indicator of social presence Indicator of interactivity Indicator of social presence	Indirect relationships (affective & cohesive exchange) are very important. Create proper learning atmosphere and high-quality dialogue/exchange environment. Learners should engage in expressing themselves to boost their network status	Kovanovic et al. (2014) *Luo et al. (2019)* Zou et al. (2021)
In-Degree Centrality	*Number of received ties* *Number of ties/(number of possible ties -1)*	*DELETED* *(non-sign. findings in the non-parametric Friedman Test)*	*Indicator of social presence* *Indicator of connectedness*	*Importance of instructor contributions for the development of social presence*	*Shea & Bidjerano (2010)* *Jimoyiannis et al. (2012)*

	Indicator of interactivity *Indicator of social presence*	*If student gets many messages he is successful at triggering others*	*Shea et al. (2013)*
	Measurement of communication	*Students with high learning presence are important partners for interaction*	*Kovanovic et al. (2014)*
	Indicator of influence	*Increase the messages sent to all students during the knowledge construction process.*	*Shea et al. (2014)*
	Indicator of influence	*sociability provides a necessary level of facilitation to help students build knowledge*	*Wicks et al. (2015)*
	Measurement of regular commitment		*Tirado et al. (2015)*
	Indicator of interactivity	*Individual performance on cognitive presence can be explained.*	*Jimoyiannis & Tsiotakis (2017)*
	Indicator of interactivity	*Active engagement enhances meaningful and sustainable learning processes*	*Jo et al. (2017)*
	Indicator of social presence		

			Indicator of social presence	*Core students' interactive behavior influence inquiry learning in group.*	*Luo et al. (2019)*
					Tirado-Morueta et al. (2019)
					Zou et al. (2021)
Out-Degree Centrality	*Number of ties sent*	*DELETED*	*Indicator of social presence*		*Kovanovic et al. (2014)*
	Number of ties/(number of possible ties -1)	*(non-sign. findings in the non-parametric Friedman Test)*	*Indicator of influence*	*sociability provides a necessary level of facilitation to help students build knowledge*	*Shea et al. (2014)*
			Indicator of prestige	*Students engage more in discussion when action is required*	*Wicks et al. (2015)*
			Indicator of interactivity	*Active engagement enhances meaningful and sustainable learning processes*	*Jimoyiannis & Tsiotakis (2017)*
			Indicator of interactivity	*Core students' interactive behavior influence inquiry learning in group.*	*Luo et al. (2019)*
			Indicator of social presence		*Papanikolaou et al. (2020)*
			Indicator of social presence		

					Tirado-Morueta et al. (2019)
Betweenness Centrality	*Degree to which ego lies on the shortest geodesic path between pairs of actors in the network* *Counting the numbers of times an actor lies on the shortest paths connecting all other actors in the network*	*DELETED* *(non-sign. findings in the non-parametric Friedman Test)*	*Indicator for social presence* *Indicator of influence* *Indicator for social presence*	*Learners should engage in expressing themselves to boost their network status*	*Kovanovic et al. (2014)* *Luo et al. (2019)* *Zou et al. (2021)*
Hierarchy	*Degree to which Constraint is focused in single alters* *Calculation adds the degree to which ego is connected to alters in egos' network*	*DELETED* *(non-sign. findings in the non-parametric Friedman Test)*	*Indicator of social presence*		*Norz et al. (2023)*
Size	*Relation between ego and alter—How many actors are directly connected to ego* *(Relational Data)—Number of Actors connected to ego*	*DELETED* *(because of pedagogical considerations:* *since here a mere summation of the number of students takes place we decided to focus on other indicators e.g., Ties—which in weighted networks deliver*	*Indicator of social presence*	*Difficult to build social ties in larger groups*	*Norz et al. (2023)*

		more reliable information of students interactivity)		
Diameter	*The longest path between actors in ego's network* *Shortest distance between most distant nodes*	*DELETED* *(non-sign. findings in the path analysis)*		
Constraint	*Degree to which actors in ego's network are connected to each other* *Degree to which actors are connected to others in ego's' network*	*DELETED* *(non-sign. findings in the non-parametric Friedman Test)*	*Indicator of social presence*	*Norz et al. (2023)*

Note. Column Description & Measurement adapted from “Social Network Analysis and Education: Theory, Methods and Applications” by B. V. Carolan (2014), p. 147–16.

Appendix B

Absolute and Relative Frequencies of Identified Labels after Manual Coding over Three Student Groups and Five Weeks Course Duration in the Groups

		Module 1 (n =1,256 postings)		Module 2 (n = 882 postings)		Module 3 (n = 935 postings)	
Week	Assigned Code	Frequency	%	Frequency	%	Frequency	%
1	Open Communication	466	55.08	456	46.10	206	48.47
	Affective Expression	318	37.59	400	40.45	154	36.23
	Group Cohesion	62	7.33	133	13.45	65	15.30
	Number of codes	846		989		425	
2	Open Communication	341	53.87	322	48.28	364	56.09
	Affective Expression	219	34.60	269	40.33	211	32.51
	Group Cohesion	73	11.53	76	11.39	74	11.40
	Number of codes	633		667		649	
3	Open Communication	330	55.28	285	44.19	361	53.96
	Affective Expression	184	30.82	258	40.00	213	31.84
	Group Cohesion	83	13.90	102	15.81	95	14.20
	Number of codes	597		645		669	
4	Open Communication	307	54.24	163	43.24	306	51.00
	Affective Expression	158	27.92	167	44.29	216	36.00
	Group Cohesion	101	17.84	47	12.47	78	13.00
	Number of codes	566		377		600	
5	Open Communication	214	56.61	159	51.96	325	51.18
	Affective Expression	120	31.75	126	41.18	236	37.17
	Group Cohesion	44	11.64	21	6.86	74	11.65
	Number of codes	378		306		635	
	Overall number of codes	3,020		2,984		2,978	

Appendix C

Manual Coding of Students' Posts for Each Student (N = 49) on Weekly Basis over the Five Weeks Course Duration

UserId	Affective Expression					Open Communication					Group Cohesion				
	WK 1	**WK 2**	**WK 3**	**WK 4**	**WK 5**	**WK 1**	**WK 2**	**WK 3**	**WK 4**	**WK 5**	**WK 1**	**WK 2**	**WK 3**	**WK 4**	**WK 5**
S1	0.50	0.58	0.53	0.59	0.64	0.67	0.67	0.59	0.59	0.57	0.50	0.25	0.18	0.18	0.25
S2	0.38	0.39	0.34	0.47	0.44	0.63	0.72	0.69	0.71	0.70	0.13	0.06	0.11	0.18	0.16
S3	1.00	0.87	0.86	0.86	0.84	0.83	0.87	0.86	0.86	0.85	0.75	0.68	0.50	0.66	0.63
S4	0.83	0.86	0.87	0.88	0.85	0.75	0.76	0.77	0.76	0.78	0.92	0.72	0.59	0.76	0.73
S5	1.00	0.81	0.77	0.78	0.73	0.60	0.69	0.74	0.73	0.73	0.20	0.31	0.30	0.38	0.33
S6	0.63	0.75	0.70	0.78	0.76	0.50	0.60	0.63	0.68	0.67	0.25	0.20	0.14	0.16	0.14
S7	0.88	0.82	0.85	0.86	0.87	0.75	0.76	0.82	0.80	0.80	0.75	0.65	0.36	0.45	0.45
S8	1.00	0.96	0.90	0.92	0.92	0.71	0.75	0.74	0.76	0.74	0.71	0.58	0.45	0.57	0.57
S9	0.83	0.73	0.75	0.75	0.70	1.00	0.93	0.88	0.88	0.84	0.00	0.33	0.22	0.28	0.23
S10	0.80	0.41	0.45	0.49	0.56	0.80	0.71	0.74	0.77	0.77	0.20	0.24	0.21	0.28	0.23
S11	0.92	0.64	0.73	0.74	0.71	0.75	0.76	0.78	0.79	0.80	0.33	0.28	0.21	0.32	0.37
S12	0.86	0.62	0.53	0.62	0.54	0.71	0.69	0.68	0.69	0.71	0.43	0.23	0.15	0.19	0.14
S13	1.00	0.80	0.72	0.72	0.70	0.70	0.72	0.74	0.76	0.74	0.60	0.52	0.46	0.52	0.49
S14	0.80	0.82	0.73	0.74	0.75	0.80	0.76	0.77	0.79	0.79	0.30	0.35	0.26	0.31	0.31
S15	0.83	0.71	0.68	0.74	0.75	0.67	0.79	0.79	0.84	0.84	0.50	0.33	0.28	0.42	0.45
S16	0.67	0.59	0.52	0.55	0.55	0.67	0.76	0.71	0.68	0.62	0.17	0.18	0.23	0.23	0.17
S17	0.88	0.80	0.70	0.72	0.72	0.58	0.68	0.71	0.71	0.71	0.25	0.20	0.18	0.24	0.22
S18	0.65	0.66	0.71	0.69	0.67	0.73	0.71	0.71	0.69	0.69	0.27	0.26	0.27	0.29	0.27
S19	0.63	0.67	0.76	0.71	0.70	0.63	0.67	0.68	0.61	0.61	0.05	0.07	0.12	0.14	0.13
S20	0.86	0.89	0.90	0.90	0.92	0.79	0.74	0.76	0.75	0.76	0.57	0.52	0.44	0.48	0.46
S21	1.00	1.00	0.93	0.94	0.94	0.67	0.77	0.78	0.75	0.75	0.53	0.42	0.50	0.52	0.55
S22	0.75	0.74	0.78	0.75	0.74	0.92	0.82	0.84	0.83	0.83	0.36	0.38	0.32	0.36	0.35
S23	0.81	0.86	0.82	0.79	0.81	0.56	0.62	0.69	0.69	0.70	0.25	0.24	0.16	0.21	0.18
S24	0.96	0.93	0.94	0.95	0.94	0.83	0.86	0.89	0.88	0.88	0.58	0.43	0.41	0.49	0.48

S25	0.90	0.92	0.92	0.92	0.92	0.91	0.84	0.86	0.85	0.86	0.58	0.53	0.41	0.49	0.47
S26	0.83	0.78	0.76	0.83	0.82	0.50	0.67	0.71	0.74	0.75	0.50	0.67	0.43	0.52	0.43
S27	0.57	0.57	0.63	0.62	0.53	0.50	0.50	0.47	0.50	0.53	0.21	0.21	0.23	0.23	0.20
S28	0.54	0.55	0.54	0.54	0.51	0.67	0.65	0.65	0.66	0.64	0.13	0.10	0.10	0.15	0.13
S29	0.71	0.62	0.60	0.57	0.58	0.76	0.74	0.76	0.74	0.70	0.10	0.15	0.19	0.22	0.22
S30	0.63	0.77	0.73	0.67	0.64	0.50	0.73	0.73	0.69	0.69	0.13	0.23	0.21	0.28	0.29
S31	0.64	0.73	0.65	0.63	0.61	0.73	0.73	0.71	0.76	0.75	0.09	0.27	0.18	0.26	0.23
S32	0.67	0.50	0.57	0.51	0.50	0.78	0.72	0.80	0.80	0.78	0.11	0.17	0.17	0.26	0.23
S33	0.78	0.78	0.78	0.78	0.78	0.44	0.44	0.44	0.44	0.44	0.00	0.00	0.00	0.00	0.00
S34	0.56	0.50	0.40	0.44	0.43	0.81	0.79	0.80	0.87	0.83	0.13	0.17	0.13	0.17	0.15
S35	0.64	0.65	0.62	0.58	0.58	0.64	0.70	0.73	0.79	0.75	0.27	0.15	0.11	0.24	0.25
S36	0.71	0.68	0.70	0.74	0.71	0.71	0.75	0.79	0.78	0.78	0.47	0.50	0.42	0.62	0.61
S37	0.76	0.78	0.81	0.81	0.81	0.90	0.86	0.83	0.86	0.86	0.10	0.16	0.23	0.34	0.35
S38	0.80	0.74	0.74	0.72	0.73	0.67	0.67	0.68	0.72	0.68	0.20	0.19	0.18	0.26	0.25
S39	0.83	0.82	0.79	0.81	0.81	0.78	0.79	0.79	0.75	0.74	0.22	0.30	0.27	0.37	0.39
S40	0.70	0.70	0.69	0.67	0.66	0.70	0.68	0.67	0.70	0.69	0.15	0.14	0.09	0.13	0.12
S41	0.57	0.54	0.57	0.54	0.49	0.74	0.78	0.78	0.79	0.80	0.13	0.17	0.10	0.24	0.25
S42	0.52	0.56	0.57	0.63	0.65	0.83	0.80	0.81	0.83	0.82	0.14	0.22	0.20	0.28	0.25
S43	0.77	0.79	0.81	0.76	0.76	0.54	0.54	0.50	0.55	0.61	0.08	0.08	0.07	0.07	0.15
S44	0.64	0.70	0.65	0.56	0.52	0.79	0.70	0.76	0.81	0.80	0.14	0.35	0.23	0.38	0.38
S45	0.73	0.69	0.71	0.67	0.65	0.73	0.77	0.75	0.74	0.74	0.14	0.26	0.25	0.26	0.25
S46	0.50	0.71	0.63	0.68	0.71	0.50	0.71	0.74	0.73	0.67	0.67	0.50	0.55	0.59	0.58
S47	0.67	0.76	0.76	0.74	0.78	0.60	0.62	0.66	0.66	0.63	0.07	0.10	0.11	0.14	0.15
S48	0.80	0.75	0.83	0.77	0.74	0.50	0.42	0.56	0.59	0.56	0.30	0.25	0.18	0.18	0.15
S49	0.78	0.79	0.71	0.64	0.61	0.61	0.71	0.73	0.80	0.80	0.28	0.32	0.24	0.42	0.43

Appendix D

Tables D1–D5

Indicators of Social Network Analysis on Egocentric Level for Each Student (N = 49) on Weekly Basis for Each Week Of Five Weeks Course Duration

Table D1

	Week 1												
UserId	**Size**	**Ties**	**Density**	**Diameter**	**nBroke**	**Constraint**	**Out.Cl.**	**In.Cl.**	**InDegr**	**OutDegr**	**Hierarchy**	**Efficiency**	**Betweenn.**
S1	7	12	0.286	0	0.71	0.498	0.143	0.609	0.167	0.000	0.102	0.733	0.000
S2	4	3	0.250	0	0.75	0.642	0.389	0.280	0.024	0.095	0.126	0.650	7.967
S3	6	7	0.233	0	0.77	0.346	0.452	0.438	0.190	0.167	0.024	0.769	42.949
S4	3	1	0.167	0	0.83	0.488	0.341	0.333	0.048	0.167	0.168	0.843	13.763
S5	1	0	0.000	0	0.00	0.000	0.259	0.259	0.071	0.024	1.000	1.000	0.000
S6	6	7	0.233	0	0.77	0.465	0.467	0.368	0.095	0.119	0.104	0.694	35.531
S7	5	7	0.350	0	0.65	0.651	0.326	0.424	0.119	0.048	0.140	0.571	9.341
S8	5	2	0.100	0	0.90	0.442	0.424	0.350	0.048	0.071	0.031	0.840	26.374
S9	4	3	0.250	0	0.75	0.628	0.389	0.311	0.048	0.048	0.004	0.750	5.403
S10	3	1	0.167	0	0.83	0.540	0.350	0.311	0.048	0.071	0.210	0.867	5.586
S11	3	1	0.167	0	0.83	0.580	0.412	0.255	0.095	0.119	0.238	0.800	6.227
S12	5	6	0.300	0	0.70	0.691	0.333	0.389	0.095	0.071	0.250	0.605	4.579
S13	5	5	0.250	0	0.75	0.583	0.378	0.269	0.071	0.119	0.094	0.792	15.568
S14	3	1	0.167	0	0.93	0.643	0.378	0.311	0.095	0.095	0.451	0.879	10.165
S15	4	2	0.167	0	0.83	0.563	0.326	0.311	0.048	0.048	0.000	0.750	3.938
S16	3	1	0.167	0	0.83	0.611	0.440	0.268	0.011	0.023	0.052	0.778	1.667
S17	8	28	0.500	0	0.50	0.592	0.524	0.688	0.091	0.091	0.282	0.581	10.561
S18	8	33	0.589	3	0.41	0.538	0.579	0.647	0.159	0.102	0.273	0.565	9.015
S19	7	28	0.667	2	0.33	0.603	0.524	0.647	0.114	0.091	0.186	0.555	2.409

S20	6	22	0.733	2	0.27	0.696	0.500	0.550	0.148	0.068	0.226	0.517	0.227
S21	4	6	0.500	0	0.50	0.879	0.478	0.550	0.068	0.080	0.230	0.646	2.652
S22	9	37	0.514	3	0.49	0.462	0.579	0.733	0.193	0.170	0.244	0.627	10.621
S23	6	14	0.467	0	0.53	0.662	0.500	0.611	0.102	0.057	0.215	0.710	5.167
S24	6	21	0.700	2	0.30	0.618	0.524	0.647	0.170	0.114	0.173	0.538	1.909
S25	9	36	0.500	3	0.50	0.344	0.647	0.688	0.136	0.432	0.097	0.726	9.924
S26	3	2	0.333	0	0.67	0.792	0.500	0.250	0.000	0.034	0.088	0.778	0.000
S27	7	22	0.524	0	0.48	0.621	0.440	0.688	0.091	0.023	0.210	0.604	2.212
S28	9	11	0.153	0	0.85	0.323	0.453	0.353	0.071	0.071	0.187	0.824	11.107
S29	10	16	0.178	0	0.82	0.324	0.407	0.421	0.119	0.032	0.154	0.814	14.883
S30	3	0	0.000	0	1.00	0.375	0.279	0.358	0.024	0.008	0.210	1.000	0.293
S31	4	4	0.333	0	0.67	0.791	0.353	0.353	0.032	0.024	0.147	0.616	1.496
S32	4	3	0.250	0	0.75	0.708	0.320	0.316	0.008	0.024	0.163	0.750	2.512
S33	6	2	0.067	0	0.93	0.305	0.338	0.312	0.063	0.016	0.180	0.931	6.075
S34	4	2	0.167	0	0.83	0.489	0.348	0.358	0.032	0.048	0.278	0.787	2.709
S35	2	1	0.500	0	0.50	1.143	0.276	0.258	0.008	0.024	0.166	0.542	0.000
S36	8	8	0.143	0	0.86	0.379	0.444	0.329	0.024	0.056	0.124	0.819	5.913
S37	8	8	0.143	0	0.86	0.384	0.429	0.348	0.040	0.048	0.169	0.810	9.149
S38	6	2	0.067	0	0.93	0.449	0.364	0.353	0.071	0.032	0.518	0.881	3.523
S39	10	18	0.200	0	0.80	0.293	0.353	0.400	0.087	0.048	0.068	0.824	5.364
S40	9	21	0.292	0	0.71	0.324	0.421	0.393	0.056	0.111	0.171	0.793	6.438
S41	9	14	0.194	0	0.81	0.350	0.471	0.348	0.040	0.095	0.178	0.801	6.288
S42	10	23	0.256	0	0.74	0.361	0.490	0.381	0.056	0.079	0.143	0.748	20.999
S43	6	4	0.133	0	0.87	0.340	0.364	0.400	0.048	0.016	0.092	0.813	9.009
S44	5	4	0.200	0	0.80	0.562	0.369	0.320	0.024	0.024	0.102	0.767	1.649
S45	7	10	0.238	0	0.76	0.469	0.462	0.312	0.032	0.063	0.085	0.759	5.571
S46	3	0	0.000	0	1.00	0.333	0.282	0.312	0.016	0.008	0.000	1.000	0.785
S47	6	1	0.033	0	0.97	0.283	0.358	0.375	0.032	0.032	0.155	0.938	5.372
S48	5	5	0.250	0	0.75	0.477	0.400	0.293	0.008	0.040	0.029	0.817	1.194
S49	6	11	0.367	3	0.63	0.619	0.393	0.375	0.040	0.032	0.191	0.745	2.314

Table D2

	Week 2												
UserId	**Size**	**Ties**	**Density**	**Diameter**	**nBroke**	**Constraint**	**Out.Cl.**	**In.Cl.**	**InDegr**	**OutDegr**	**Hierarchy**	**Efficiency**	**Betweenn.**
S1	8	19	0.339	4	0.66	0.485	0.4520	0.700	0.092	0.020	0.126	0.700	2.355
S2	6	13	0.433	0	0.57	0.555	0.6090	0.483	0.041	0.092	0.155	0.655	1.456
S3	10	28	0.311	4	0.69	0.294	0.6670	0.609	0.173	0.153	0.044	0.797	16.960
S4	3	2	0.333	0	0.67	0.593	0.4670	0.424	0.071	0.133	0.385	0.843	1.282
S5	4	5	0.417	3	0.58	0.906	0.4520	0.519	0.092	0.061	0.554	0.731	3.284
S6	10	29	0.322	4	0.68	0.364	0.6090	0.636	0.102	0.092	0.093	0.724	13.729
S7	8	22	0.393	4	0.61	0.471	0.6096	0.583	0.071	0.061	0.100	0.595	7.031
S8	10	32	0.356	0	0.64	0.371	0.6360	0.560	0.041	0.112	0.084	0.674	10.711
S9	8	22	0.393	4	0.61	0.451	0.5600	0.519	0.071	0.041	0.074	0.710	3.722
S10	6	12	0.400	4	0.60	0.558	0.4520	0.560	0.082	0.061	0.167	0.620	2.689
S11	7	14	0.333	5	0.67	0.431	0.5830	0.483	0.092	0.102	0.137	0.744	6.327
S12	7	15	0.357	4	0.64	0.546	0.5380	0.560	0.061	0.061	0.206	0.666	3.721
S13	10	31	0.344	3	0.66	0.345	0.6360	0.636	0.112	0.112	0.060	0.724	10.361
S14	6	14	0.467	4	0.53	0.545	0.5830	0.560	0.071	0.082	0.114	0.577	3.063
S15	9	26	0.361	4	0.64	0.406	0.5830	0.583	0.092	0.082	0.083	0.695	6.714
S16	7	25	0.595	3	0.40	0.657	0.6110	0.688	0.073	0.048	0.228	0.645	1.509
S17	10	56	0.622	3	0.38	0.476	0.7330	0.917	0.145	0.103	0.264	0.583	8.346
S18	9	49	0.681	3	0.32	0.509	0.7860	0.733	0.121	0.073	0.257	0.569	6.132
S19	7	33	0.786	2	0.21	0.672	0.6880	0.688	0.079	0.073	0.247	0.524	0.675
S20	10	60	0.667	3	0.33	0.533	0.7330	0.688	0.145	0.067	0.309	0.578	2.015
S21	8	36	0.643	2	0.36	0.549	0.7330	0.611	0.067	0.103	0.209	0.594	2.584
S22	11	59	0.536	0	0.46	0.446	0.9170	0.917	0.188	0.188	0.317	0.608	17.699
S23	8	38	0.679	2	0.32	0.516	0.6880	0.733	0.103	0.061	0.146	0.693	2.571
S24	7	34	0.810	2	0.19	0.647	0.7330	0.733	0.158	0.121	0.331	0.482	1.463

S25	11	61	0.555	3	0.45	0.342	0.9170	0.786	0.158	0.412	0.195	0.705	6.390
S26	5	16	0.800	2	0.20	0.838	0.6470	0.500	0.006	0.030	0.128	0.556	0.000
S27	7	32	0.762	2	0.24	0.657	0.5000	0.688	0.048	0.012	0.200	0.572	0.615
S28	11	27	0.245	0	0.75	0.332	0.6180	0.477	0.039	0.056	0.204	0.777	5.441
S29	13	43	0.276	0	0.72	0.239	0.5680	0.724	0.134	0.035	0.069	0.812	12.884
S30	7	14	0.333	0	0.67	0.487	0.5250	0.538	0.026	0.026	0.076	0.646	3.993
S31	8	31	0.554	3	0.45	0.429	0.5120	0.512	0.048	0.030	0.029	0.645	1.490
S32	6	13	0.433	0	0.57	0.650	0.5380	0.488	0.013	0.030	0.253	0.709	0.949
S33	6	3	0.100	0	0.90	0.327	0.3820	0.457	0.035	0.009	0.143	0.931	1.300
S34	6	11	0.367	0	0.63	0.540	0.4770	0.525	0.026	0.043	0.228	0.717	1.885
S35	7	12	0.286	0	0.71	0.420	0.4770	0.512	0.026	0.030	0.049	0.780	2.559
S36	10	25	0.278	0	0.72	0.402	0.6000	0.467	0.030	0.061	0.182	0.737	5.106
S37	10	30	0.333	0	0.67	0.379	0.5380	0.538	0.052	0.056	0.153	0.691	6.367
S38	15	54	0.257	0	0.74	0.257	0.5380	0.700	0.147	0.035	0.209	0.805	11.112
S39	15	63	0.300	4	0.70	0.253	0.5000	0.700	0.100	0.048	0.147	0.781	6.878
S40	9	38	0.528	3	0.47	0.428	0.5120	0.538	0.030	0.087	0.274	0.625	1.839
S41	14	59	0.324	0	0.68	0.282	0.6770	0.583	0.039	0.100	0.096	0.739	9.370
S42	12	49	0.371	0	0.63	0.316	0.6360	0.583	0.052	0.065	0.096	0.720	11.688
S43	8	17	0.304	4	0.70	0.437	0.5530	0.553	0.030	0.043	0.196	0.692	4.056
S44	7	9	0.214	0	0.79	0.391	0.5000	0.525	0.026	0.026	0.130	0.839	4.379
S45	9	29	0.403	0	0.60	0.389	0.6360	0.404	0.022	0.074	0.088	0.689	0.926
S46	5	1	0.050	0	0.95	0.315	0.3750	0.512	0.026	0.013	0.293	0.956	1.767
S47	6	3	0.100	0	0.90	0.423	0.4670	0.538	0.022	0.030	0.126	0.844	3.707
S48	6	10	0.333	0	0.67	0.441	0.5250	0.382	0.004	0.026	0.012	0.784	0.385
S49	8	32	0.571	3	0.43	0.425	0.5830	0.553	0.043	0.048	0.014	0.654	1.681

Table D3

	Week 3												
UserId	**Size**	**Ties**	**Density**	**Diameter**	**nBroke**	**Constraint**	**Out.Cl.**	**In.Cl.**	**InDegr**	**OutDegr**	**Hierarchy**	**Efficiency**	**Betweenn.**
S1	8	24	0.429	3	0.57	0.499	0.519	0.700	0.071	0.011	0.140	0.678	0.783
S2	8	27	0.482	3	0.52	0.457	0.636	0.500	0.038	0.060	0.113	0.623	0.788
S3	11	47	0.427	4	0.57	0.341	0.737	0.700	0.126	0.115	0.132	0.710	14.594
S4	4	7	0.583	3	0.42	0.591	0.560	0.452	0.066	0.148	0.380	0.820	0.458
S5	4	5	0.417	3	0.58	0.817	0.538	0.583	0.104	0.066	0.496	0.728	2.588
S6	12	60	0.455	3	0.55	0.336	0.700	0.700	0.077	0.060	0.106	0.624	10.492
S7	11	47	0.427	4	0.57	0.360	0.700	0.667	0.060	0.088	0.112	0.691	8.818
S8	10	47	0.522	3	0.48	0.350	0.700	0.583	0.038	0.099	0.104	0.675	6.351
S9	10	42	0.467	3	0.53	0.367	0.583	0.636	0.055	0.033	0.036	0.696	2.540
S10	7	21	0.500	3	0.50	0.471	0.538	0.636	0.077	0.049	0.151	0.648	1.327
S11	9	38	0.528	3	0.47	0.398	0.667	0.636	0.066	0.082	0.097	0.621	4.426
S12	8	29	0.518	2	0.48	0.465	0.560	0.636	0.055	0.044	0.138	0.597	1.969
S13	11	56	0.509	3	0.49	0.326	0.700	0.700	0.093	0.082	0.044	0.645	5.705
S14	9	39	0.542	2	0.46	0.395	0.667	0.667	0.066	0.082	0.084	0.560	4.224
S15	10	45	0.500	3	0.50	0.374	0.667	0.700	0.093	0.066	0.063	0.621	4.719
S16	8	40	0.714	3	0.29	0.608	0.611	0.733	0.081	0.038	0.223	0.548	0.894
S17	10	64	0.711	3	0.29	0.483	0.846	0.917	0.148	0.115	0.268	0.550	7.314
S18	10	64	0.711	3	0.29	0.512	0.917	0.786	0.110	0.072	0.315	0.544	7.289
S19	8	45	0.804	2	0.20	0.636	0.786	0.688	0.096	0.091	0.303	0.509	0.690
S20	10	66	0.733	2	0.27	0.526	0.846	0.786	0.158	0.077	0.298	0.522	1.707
S21	10	67	0.744	2	0.26	0.478	0.846	0.846	0.096	0.115	0.235	0.541	4.382
S22	11	73	0.664	2	0.34	0.453	0.917	0.917	0.177	0.187	0.298	0.573	6.085
S23	9	56	0.778	2	0.22	0.480	0.786	0.786	0.110	0.072	0.150	0.620	1.154
S24	9	59	0.819	2	0.18	0.553	0.786	0.786	0.167	0.144	0.331	0.494	1.889
S25	11	74	0.673	2	0.33	0.326	0.917	0.846	0.177	0.440	0.151	0.697	2.996

S26	7	34	0.810	2	0.19	0.616	0.688	0.611	0.024	0.033	0.123	0.591	0.509
S27	7	34	0.810	2	0.19	0.733	0.550	0.688	0.048	0.010	0.314	0.491	0.547
S28	11	31	0.282	0	0.72	0.351	0.618	0.500	0.039	0.056	0.192	0.750	4.324
S29	13	52	0.333	7	0.67	0.242	0.568	0.724	0.147	0.039	0.057	0.808	8.746
S30	9	34	0.472	3	0.53	0.382	0.538	0.553	0.035	0.035	0.045	0.677	2.738
S31	9	39	0.542	3	0.46	0.407	0.525	0.525	0.052	0.035	0.055	0.648	1.214
S32	7	18	0.429	0	0.57	0.547	0.538	0.500	0.022	0.039	0.199	0.711	0.846
S33	6	4	0.133	0	0.87	0.352	0.420	0.477	0.035	0.009	0.116	0.903	1.190
S34	10	37	0.411	4	0.59	0.405	0.500	0.600	0.043	0.048	0.204	0.684	2.816
S35	8	16	0.286	0	0.71	0.383	0.488	0.583	0.035	0.035	0.060	0.762	2.720
S36	12	42	0.318	5	0.68	0.335	0.677	0.568	0.039	0.082	0.145	0.729	7.005
S37	12	53	0.402	0	0.60	0.345	0.618	0.538	0.065	0.074	0.179	0.703	5.687
S38	15	67	0.319	4	0.68	0.246	0.583	0.700	0.160	0.043	0.164	0.805	8.387
S39	17	88	0.324	3	0.68	0.236	0.568	0.808	0.108	0.061	0.129	0.776	9.697
S40	9	39	0.542	3	0.46	0.433	0.538	0.538	0.030	0.087	0.269	0.617	1.063
S41	14	65	0.357	0	0.64	0.297	0.677	0.618	0.048	0.104	0.134	0.724	7.542
S42	13	60	0.385	0	0.62	0.304	0.656	0.583	0.061	0.074	0.095	0.753	10.383
S43	8	20	0.357	4	0.64	0.437	0.568	0.568	0.030	0.043	0.150	0.662	2.367
S44	9	25	0.347	5	0.65	0.379	0.553	0.568	0.035	0.035	0.089	0.781	4.221
S45	11	42	0.382	0	0.62	0.342	0.656	0.467	0.030	0.091	0.121	0.718	1.383
S46	5	2	0.100	0	0.90	0.425	0.396	0.512	0.026	0.017	0.315	0.918	5.233
S47	8	13	0.232	0	0.77	0.390	0.525	0.538	0.026	0.039	0.059	0.797	3.751
S48	6	10	0.333	0	0.67	0.446	0.538	0.382	0.004	0.026	0.019	0.772	0.328
S49	10	47	0.522	3	0.48	0.370	0.600	0.568	0.052	0.052	0.051	0.713	1.869

Table D4

	Week 4												
UserId	**Size**	**Ties**	**Density**	**Diameter**	**nBroke**	**Constraint**	**Out.Cl.**	**In.Cl.**	**InDegr**	**OutDegr**	**Hierarchy**	**Efficiency**	**Betweenn.**
S1	8	30	0.536	3	0.46	0.494	0.519	0.700	0.076	0.009	0.125	0.688	0.137
S2	9	41	0.569	3	0.43	0.409	0.667	0.583	0.400	0.067	0.084	0.593	1.589
S3	11	52	0.473	3	0.53	0.374	0.737	0.700	0.121	0.121	0.210	0.719	11.652
S4	5	13	0.650	2	0.35	0.558	0.609	0.452	0.067	0.161	0.361	0.760	0.855
S5	4	6	0.500	3	0.50	0.887	0.538	0.583	0.098	0.063	0.481	0.624	2.217
S6	13	71	0.455	3	0.54	0.303	0.700	0.824	0.089	0.063	0.071	0.713	11.231
S7	12	60	0.455	4	0.55	0.334	0.778	0.737	0.071	0.085	0.101	0.691	10.441
S8	10	49	0.544	3	0.46	0.361	0.700	0.609	0.054	0.098	0.125	0.712	6.061
S9	10	48	0.533	3	0.47	0.378	0.609	0.636	0.058	0.040	0.082	0.711	2.832
S10	7	25	0.595	2	0.40	0.499	0.560	0.636	0.800	0.049	0.170	0.655	1.227
S11	9	39	0.542	3	0.46	0.398	0.700	0.636	0.067	0.098	0.107	0.648	3.998
S12	8	34	0.607	2	0.39	0.472	0.609	0.667	0.058	0.045	0.149	0.617	1.379
S13	11	62	0.564	2	0.44	0.326	0.737	0.700	0.094	0.080	0.045	0.670	3.894
S14	9	44	0.610	2	0.39	0.385	0.667	0.667	0.067	0.089	0.067	0.619	2.563
S15	10	49	0.544	3	0.46	0.362	0.667	0.700	0.098	0.071	0.053	0.648	3.695
S16	8	44	0.786	2	0.21	0.600	0.611	0.733	0.067	0.032	0.210	0.541	0.872
S17	10	66	0.733	2	0.27	0.476	0.846	0.917	0.134	0.103	0.260	0.579	4.434
S18	10	69	0.767	2	0.23	0.539	0.917	0.786	0.115	0.059	0.354	0.515	3.554
S19	8	46	0.821	2	0.18	0.668	0.786	0.688	0.099	0.075	0.350	0.476	0.690
S20	10	68	0.756	2	0.24	0.542	0.846	0.786	0.134	0.063	0.318	0.523	1.690
S21	10	69	0.767	2	0.23	0.490	0.846	0.846	0.083	0.095	0.247	0.547	3.390
S22	11	77	0.700	2	0.30	0.447	0.917	1.000	0.154	0.190	0.311	0.582	6.320
S23	10	66	0.733	2	0.27	0.462	0.846	0.846	0.107	0.071	0.191	0.628	2.435
S24	9	60	0.833	2	0.17	0.573	0.786	0.846	0.158	0.123	0.372	0.491	1.866
S25	11	79	0.718	2	0.28	0.318	0.917	0.846	0.162	0.431	0.154	0.705	2.670

S26	8	41	0.732	2	0.27	0.571	0.733	0.688	0.028	0.032	0.160	0.651	1.281
S27	9	53	0.736	2	0.26	0.613	0.647	0.688	0.055	0.024	0.321	0.492	1.706
S28	12	59	0.447	0	0.55	0.333	0.618	0.568	0.052	0.056	0.115	0.699	2.706
S29	14	80	0.440	3	0.56	0.250	0.636	0.750	0.165	0.056	0.056	0.738	5.072
S30	11	58	0.527	3	0.47	0.327	0.600	0.583	0.056	0.043	0.048	0.712	1.764
S31	11	67	0.609	2	0.39	0.360	0.600	0.553	0.069	0.052	0.093	0.616	1.165
S32	7	22	0.524	0	0.48	0.531	0.538	0.525	0.026	0.056	0.141	0.654	0.459
S33	6	6	0.200	0	0.80	0.411	0.438	0.500	0.035	0.009	0.100	0.881	0.815
S34	15	97	0.462	3	0.54	0.264	0.600	0.700	0.100	0.069	0.100	0.695	3.455
S35	13	62	0.397	4	0.60	0.283	0.618	0.600	0.039	0.065	0.059	0.739	3.914
S36	15	80	0.381	4	0.62	0.306	0.750	0.600	0.087	0.100	0.189	0.689	3.914
S37	14	85	0.467	0	0.53	0.320	0.656	0.600	0.078	0.095	0.180	0.664	5.674
S38	15	87	0.414	3	0.59	0.251	0.636	0.700	0.165	0.056	0.124	0.760	4.832
S39	17	116	0.426	3	0.57	0.233	0.636	0.808	0.147	0.074	0.083	0.722	6.180
S40	12	73	0.553	2	0.45	0.344	0.553	0.656	0.061	0.095	0.191	0.638	1.114
S41	17	114	0.419	4	0.58	0.258	0.700	0.750	0.091	0.134	0.137	0.716	9.169
S42	14	86	0.473	3	0.53	0.285	0.677	0.600	0.069	0.100	0.077	0.711	4.998
S43	8	21	0.375	4	0.63	0.421	0.568	0.568	0.030	0.056	0.143	0.675	1.214
S44	13	63	0.404	4	0.60	0.270	0.636	0.618	0.052	0.074	0.043	0.763	5.439
S45	14	85	0.467	0	0.53	0.285	0.724	0.500	0.030	0.113	0.093	0.725	0.924
S46	5	4	0.200	0	0.80	0.460	0.438	0.553	0.026	0.017	0.254	0.882	1.092
S47	11	43	0.391	0	0.61	0.319	0.618	0.583	0.030	0.052	0.048	0.738	3.781
S48	8	22	0.393	0	0.61	0.408	0.538	0.500	0.017	0.026	0.037	0.711	0.729
S49	12	73	0.553	3	0.45	0.321	0.656	0.618	0.069	0.095	0.071	0.665	2.168

Table D5

	Week 5												
UserId	**Size**	**Ties**	**Density**	**Diameter**	**nBroke**	**Constraint**	**Out.Cl.**	**In.Cl.**	**InDegr**	**OutDegr**	**Hierarchy**	**Efficiency**	**Betweenn.**
S1	8	31	0.554	3	0.45	0.494	0.519	0.700	0.068	0.119	0.693	0.006	0.137
S2	9	45	0.625	2	0.38	0.419	0.667	0.583	0.032	0.134	0.636	0.058	1.141
S3	11	57	0.518	2	0.48	0.406	0.737	0.700	0.097	0.262	0.718	0.120	8.409
S4	6	18	0.600	3	0.40	0.579	0.636	0.500	0.079	0.426	0.690	0.143	1.125
S5	4	8	0.667	2	0.33	0.950	0.538	0.583	0.097	0.503	0.442	0.058	0.788
S6	13	76	0.487	2	0.51	0.302	0.700	0.824	0.071	0.066	0.739	0.052	9.826
S7	12	67	0.508	3	0.49	0.323	0.778	0.737	0.071	0.102	0.708	0.084	8.925
S8	11	57	0.518	3	0.48	0.346	0.778	0.667	0.065	0.087	0.730	0.088	9.573
S9	10	52	0.578	3	0.42	0.377	0.636	0.636	0.055	0.111	0.717	0.042	1.976
S10	8	34	0.607	2	0.39	0.458	0.636	0.667	0.075	0.185	0.718	0.049	1.713
S11	9	44	0.611	2	0.39	0.408	0.700	0.667	0.062	0.132	0.626	0.081	2.376
S12	10	54	0.600	2	0.40	0.406	0.636	0.700	0.055	0.126	0.665	0.042	2.002
S13	11	67	0.609	2	0.39	0.330	0.737	0.737	0.075	0.044	0.694	0.068	4.027
S14	9	45	0.625	2	0.38	0.386	0.700	0.667	0.049	0.046	0.666	0.081	2.764
S15	11	64	0.582	2	0.42	0.344	0.700	0.737	0.091	0.090	0.649	0.068	3.458
S16	9	54	0.750	2	0.25	0.543	0.647	0.733	0.075	0.211	0.577	0.036	1.314
S17	10	68	0.756	2	0.24	0.481	0.846	0.917	0.134	0.263	0.567	0.103	3.458
S18	10	69	0.767	2	0.23	0.549	0.917	0.846	0.123	0.365	0.503	0.059	3.465
S19	9	56	0.778	2	0.22	0.644	0.786	0.733	0.107	0.386	0.470	0.075	1.424
S20	10	70	0.778	2	0.22	0.550	0.846	0.786	0.138	0.331	0.507	0.063	1.647
S21	10	71	0.789	2	0.21	0.495	0.846	0.846	0.083	0.252	0.537	0.095	2.911
S22	11	78	0.709	2	0.29	0.457	1.000	1.000	0.158	0.332	0.563	0.202	5.845
S23	10	67	0.744	2	0.26	0.459	0.846	0.846	0.111	0.193	0.628	0.079	2.305
S24	9	61	0.847	2	0.15	0.582	0.786	0.846	0.158	0.379	0.485	0.123	1.647
S25	11	81	0.736	2	0.26	0.317	0.917	0.846	0.170	0.156	0.703	0.451	2.451

S26	8	42	0.750	2	0.25	0.572	0.733	0.688	0.028	0.162	0.638	0.032	1.168
S27	9	55	0.764	2	0.24	0.619	0.647	0.688	0.055	0.325	0.487	0.024	1.455
S28	13	80	0.513	3	0.49	0.317	0.618	0.600	0.095	0.123	0.656	0.061	2.045
S29	16	126	0.525	3	0.47	0.232	0.677	0.778	0.186	0.049	0.708	0.065	4.351
S30	12	70	0.530	3	0.47	0.327	0.656	0.583	0.065	0.096	0.684	0.061	1.802
S31	12	84	0.636	2	0.36	0.343	0.600	0.618	0.082	0.102	0.595	0.061	0.804
S32	9	40	0.556	0	0.44	0.447	0.568	0.538	0.030	0.138	0.630	0.065	0.493
S33	6	7	0.233	0	0.77	0.451	0.438	0.512	0.035	0.112	0.845	0.009	0.471
S34	16	129	0.538	3	0.46	0.251	0.636	0.700	0.113	0.095	0.673	0.082	2.267
S35	16	102	0.425	3	0.57	0.262	0.618	0.656	0.056	0.120	0.710	0.087	3.686
S36	17	127	0.467	3	0.53	0.264	0.808	0.656	0.100	0.144	0.662	0.126	6.367
S37	14	96	0.527	0	0.47	0.319	0.656	0.618	0.082	0.159	0.639	0.100	5.313
S38	17	133	0.489	3	0.51	0.237	0.700	0.724	0.169	0.118	0.719	0.069	5.569
S39	17	133	0.489	3	0.51	0.225	0.656	0.840	0.186	0.060	0.715	0.087	5.066
S40	13	92	0.590	2	0.41	0.326	0.583	0.677	0.078	0.170	0.612	0.100	0.823
S41	18	134	0.438	4	0.56	0.239	0.724	0.808	0.104	0.110	0.706	0.173	8.655
S42	15	105	0.500	3	0.50	0.275	0.677	0.636	0.087	0.091	0.688	0.108	3.794
S43	9	32	0.444	4	0.56	0.413	0.600	0.568	0.035	0.159	0.684	0.082	1.517
S44	15	97	0.462	3	0.54	0.256	0.677	0.636	0.065	0.080	0.717	0.100	5.093
S45	15	104	0.495	0	0.50	0.272	0.724	0.525	0.052	0.098	0.714	0.126	1.344
S46	5	4	0.200	0	0.80	0.540	0.447	0.568	0.026	0.290	0.840	0.017	1.039
S47	12	64	0.485	0	0.52	0.308	0.636	0.583	0.030	0.062	0.739	0.061	3.238
S48	10	42	0.467	0	0.53	0.369	0.600	0.525	0.022	0.032	0.718	0.035	0.909
S49	13	95	0.609	2	0.39	0.311	0.677	0.618	0.074	0.082	0.637	0.100	1.784

Appendix E

Show Case—Module 1

Module 1 is one of the first course modules in the overall master's courses. Students taking part in this Module are new to the teachers, do not know each other well, and are new to the learning management system, as well as the affordances and design of the instructional tasks in online learning.

Development of Social Presence

In Figure E1, the progression of social presence indicators expressed in percentage within module 1, as measured by manual coding, are shown. All indicators of social presence showed significant results in the non-parametric Friedman test in Module 1. Affective Expression (AF) increased significantly from week one to week two, after which it decreased significantly from week two to week five ($\chi 2$ (4)=15.53, p = .004). Open Communication (OC) increased from week one till week four and then dropped ($\chi 2$ (4) = 16.92, p = .002). Group cohesion (GC) showed a significant wave-like progression: From week one to week two, these indicators increased, decreased from week two to week three, increased again from week three to week four, and decreased again from week four to week five ($\chi 2$ (4) = 33.61, p = .000).

Instructional Tasks

The progression of social presence is understood more deeply when looking into the scaffolding of the instructional tasks in Module 1. In the first week students were asked to open dialogue with each other and to exchange ideas. One instructional task in week one says: "*Read some of the contributions of others. Do you find commonalities and maybe even a "learning twin"? If so, suggest how you might collaborate in the module process for mutual benefit. Respond to at least one other contribution—or more, of course. Make sure together that everyone gets a response if possible.*" which is an intention to promote interaction between students and therefore social presence. The kink in almost all mean values of the indicators of social presence in week 2 can be explained by one of the assignments in week 2: "*A mandatory professional dialogue is not necessary here."* Apparently, in our show case, Module 1, the development of social presence is strongly dependent on the wording and tasks written in the instructional tasks.

In creating instructional tasks, it seems important to articulate what students need to do and how they need to interact in a meaningful way. As described earlier, in week one students are asked to read, respond, react, and work together, which has promoted interactivity and therefore all social presence indicators. The wording of the assignment *"respond to at least one other contribution"* and *"make sure together that everyone gets a response if possible"* supported abalance between in-coming and out-going messages. This was also seen over all modules, which might be a particularfeature of this master's course and the small group sizes given.

Development of Social Network Analysis Indicators

In Figure E2 the progression of indicators in Module 1 is shown. Many students took over brokerage positions in the first week. NBroke (M = 0.81) as well as Efficiency (M = 0.80) are very high, whereas Density is low (M = 0.18). It is explainable as the Module has just started and students are invitated through the assignments to initially post in an invididual discussion thread. The dialogue begins only afterwards. At the end of the five weeks course duration

NBroke (M = 0.51), as well as Efficiency (M = 69) significantly decreased, whereas Density (M = 0.48) significantly increased. Additionally, we see that the indicators In-Closeness and Out-Closeness develop to the same extent. Here we see how multicollinear social presence is and how important it is to consider several factors: The number of incoming messages is naturally influenced by the number of outgoing messages and vice versa. In terms of a balanced and active community, it is important that these indicators are reciprocal, which means that outgoing messages should be followed by incoming messages and vice versa.

Figure E1

Development of Social Presence Indicators Found by Manual Coding in the Three Cateogries of Manual Coding Over the Five Weeks Course Duration in Module 1 in Percentage

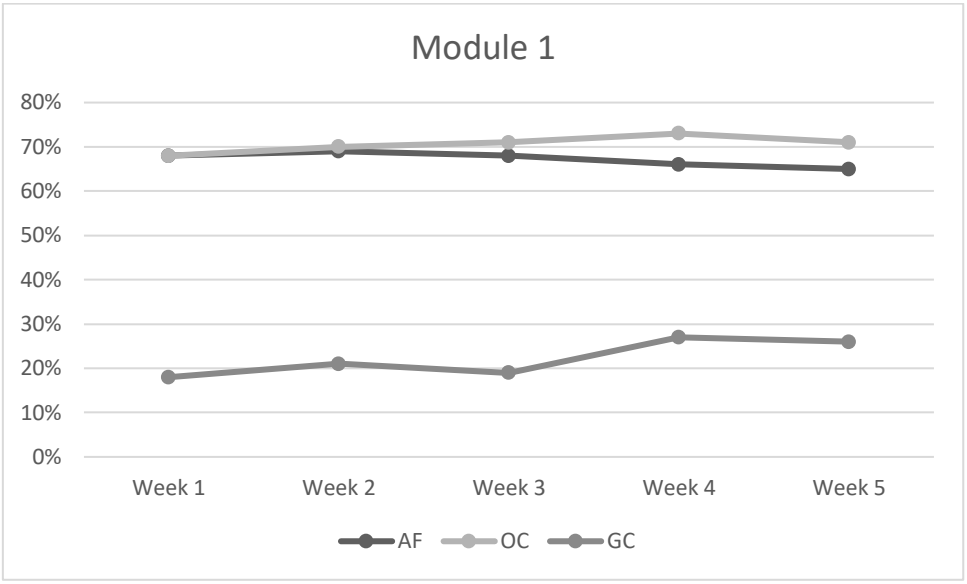
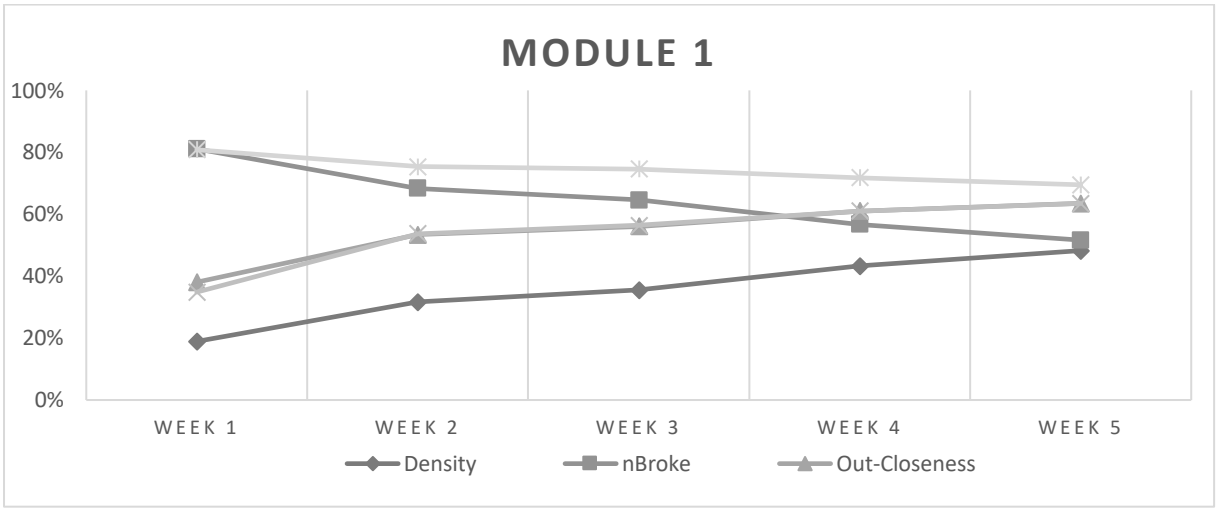


Figure E2

Development of SNA Indicators (Density, nBroke, Out-closeness, In-Closeness, Efficiency) Over the Five Weeks Course Duration in Module 1 in Percentage.



Note. For a definition and discussion of pedagogical relevance of each indicator see Appendix A.

Appendix F

Means, Standard Deviations, p-values, Bonferroni Corrected p-values, Test Statistics (Friedmans' Q), Degrees of Freedom (df) and Sample Size (N) of Non-parametric Friedman Test for all Modules and Weeks 1–5 for the Indicators of Social Network Analysis

Module	Measure	Week 1 M(SD)	Week 2 M(SD)	Week 3 M(SD)	Week 4 M(SD)	Week 5 M(SD)	*p*	*p* Bonf.	Q	df	N
1	Ties	7.6 (7)	26 (18.69)	36.5 (22.2)	63.8 (32.16)	86.2 (40.14)	p < .0001	p < .0001	87.61	4	22
2	Ties	20.8 (12.65)	41.6 (15.01)	56.3 (14.51)	61.5 (12.73)	64.3 (11.11)	p < .0001	p < .0001	47.81	4	12
3	Ties	3.9 (3.36)	18.9 (9.25)	35.6 (16.4)	41.5 (17.82)	47.9 (18.89)	p < .0001	p < .0001	59.81	4	15
1	Density	0.19 (0.12)	0.31 (0.13)	0.35 (0.11)	0.43 (0.09)	0.48 (0.10)	p < .0001	p < .0001	76.00	4	22
2	Density	0.51 (0.16)	0.68 (0.09)	0.74 (0.05)	0.75 (0.04)	0.76 (0.03)	p < .0001	p < .0001	32.23	4	12
3	Density	0.20 (0.08)	0.37 (0.04)	0.49 (0.05)	0.55 (0.069	0.58 (0.05)	p < .0001	p < .0001	56.20	4	15
1	nBroke	0.81 (0.12)	0.68 (0.13)	0.64 (0.11)	0.56 (0.09)	0.51 (0.10)	p < .0001	p < .0001	76.16	4	22
2	nBroke	0.48 (0.15)	0.32 (0.09)	0.25 (0.06)	0.24 (0.04)	0.23 (0.03)	p < .0001	p < .0001	31.59	4	12
3	nBroke	0.73 (0.21)	0.63 (0.04)	0.51 (0.04)	0.45 (0.06)	0.42 (0.05)	p < .0001	p < .0001	49.83	4	15
1	Constraint	0.46 (0.20)	0.39 (0.09)	0.36 (0.07)	0.33 (0.07)	0.32 (0.08)	p < .0001	p < .0001	33.52	4	22
2	Constraint	0.61 (0.14)	0.57 (0.13)	0.53 (0.11)	0.53 (0.09)	0.52 (0.08)	.026	.286	11.06	4	12
3	Constraint	0.51 (0.17)	0.48 (0.14)	0.44 (0.13)	0.44 (0.14)	0.44 (0.16)	p < .0001	p < .0001	19.83	4	15
1	In-Closeness	0.35 (0.04)	0.54 (0.09)	0.56 (0.09)	0.61 (0.08)	0.64 (0.09)	p < .0001	p < .0001	84.48	4	22

2	In-Closeness	0.58 (0.16)	0.72 (0.12)	0.78 (0.09)	0.80 (0.09)	0.81 (0.09)	p < .0001	p < .0001	39.11	4	12
3	In-Closeness	0.35 (0.09)	0.56 (0.07)	0.63 (0.07)	0.65 (0.08)	0.67 (0.07)	p < .0001	p < .0001	55.41	4	15
1	In-Degree C.	0.04 (0.02)	0.04 (0.02)	0.05 (0.04)	0.07 (0.04)	0.08 (0.05)	p < .0001	p < .0001	53.40	4	22
2	In-Degree C.	0.11 (0.06)	0.11 (0.06)	0.12 (0.05)	0.11 (0.04)	0.11 (0.04)	.229	1	5.62	4	12
3	In-Degree C.	0.08 (0.04)	0.08 (0.03)	0.07 (0.02)	0.15 (0.20)	0.07 (0.02)	.019	.209	11.81	4	15
1	Hierarchy	0.16 (0.10)	0.14 (0.08)	0.13 (0.08)	0.11 (0.06)	0.11 (0.05)	.062	.682	8.95	4	22
2	Hierarchy	0.19 (0.07)	0.24 (0.06)	0.25 (0.07)	0.27 (0.07)	0.28 (0.08)	.002	.022	16.95	4	12
3	Hierarchy	0.19 (0.25)	0.16 (0.14)	0.15 (0.13)	0.15 (0.12)	0.16 (0.13)	.688	1	2.26	4	15
1	Efficiency	0.80 (0.10)	0.75 (0.09)	0.75 (0.07)	0.72 (0.06)	0.69 (0.06)	p < .0001	p < .0001	51.74	4	22
2	Efficiency	0.63 (0.09)	0.59 (0.06)	0.56 (0.06)	0.56 (0.07)	0.55 (0.07)	p < .0001	p < .0001	26.13	4	12
3	Efficiency	0.77 (0.11)	0.70 (0.07)4	0.66 (0.06)	0.67 (0.04)	0.67 (0.07)	p < .0001	p < .0001	22.01	4	15
1	Betweenness C.	5.57 (5.10)	4.53 (3.75)	4.25 (3.13)	3.21 (2.30)	3.02 (2.25)	.016	.176	12.15	4	22
2	Betweenness C.	4.70 (4.15)	4.16 (5.00)	2.95 (2.64)	2.57 (1.63)	2.42 (1.35)	.087	.957	8.13	4	12
3	Betweenness C.	12.49 (12.77)	6.23 (4.74)	4.64 (4.04)	4.25 (3.85)	3.88 (3.469	p < .0001	p < .0001	24.04	4	15
1	Out-Closeness	0.38 (0.06)	0.53 (0.08)	0.56 (0.07)	0.61 (0.08)	0.64 (0.08)	p < .0001	p < .0001	83.56	4	22
2	Out-Closeness	0.52 (0.06)	0.72 (0.12)	0.79 (0.12)	0.81 (0.10)	0.82 (0.11)	p < .0001	p < .0001	42.52	4	12
3	Out-Closeness	0.36 (0.80)	0.56 (0.07)	0.63 (0.07)	0.65 (0.08)	0.67 (0.08)	p < .0001	p < .0001	56.94	4	15
1	Out-Degree C.	0.04 (0.03)	0.04 (0.02)	0.05 (0.02)	0.07 (0.03)	0.08 (0.04)	p < .0001	p < .0001	54.60	4	22
2	Out-Degree C.	0.11 (0.11)	0.11 (0.11)	0.12 (0.11)	0.11 (0.11)	0.11 (0.12)	.155	1	6.68	4	12

3	Out-Degree C.	0.08 (0.04)	0.08 (0.03)	0.07 (0.03)	0.08 (0.04)	0.07 (0.03)	.008	.088	13.65	4	15