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Methods/Theory Research Brief: Findings from a Scoping Review of Social Network Analysis in Engineering Education

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Methods/Theory Research Brief: A Scoping Review of Social Network Analysis in Engineering Education

Interpersonal relationships are a key aspect of success for engineers [1]-[3]. As elaborated by theories such as the Network Theory of Social Capital [4], [5], an individual's access to certain resources can be indirectly increased through access to other individuals with those resources. Considering knowledge as a resource, this idea parallels the earlier established social constructivist epistemology, where access to individuals who hold new knowledge is a key part of effectively integrating knowledge into a learner's existing construction [6]-[9]. Over the last several decades, engineering education has increasingly recognized the importance of interpersonal connections [10] and has even included "the ability to effectively work in teams" as an ABET outcome [11].

Despite knowing interpersonal relationships are important for effective engineering, how to establish or incentivize groups positively, within and outside the classroom, is a persistent question. Thus, a breadth of engineering education research has sought to identify effective methods for assessing interpersonal networks' existence, evolution, and relationship to outcomes [12]-[17]. Among the many methods for studying interpersonal networks, Social Network Analysis (SNA) has emerged as a particularly effective method. Specifically, SNA borrows from the larger field of network analysis [18], [19] by assigning individuals in a network as graph vertices (V) and connections between the individuals as graph edges (E). With a graph (G) summarizing the individuals and connections in the network: $G = (V, E)$, researchers apply relevant network-theoretic mathematics to quantitatively describe traits of the larger network, sub-networks, and individuals in the network.

Researchers applying SNA have quantitatively identified relationships between interactions and outcomes including the relationship between engineering students' engagement with instructors and grade performance [20]-[24], the likelihood of retention according to integration at an institution [25]-[27], and even assessed STEM educators' community involvement [28]. However, across these studies, our review of the relevant literature for prior study purposes identified redundancies, a relative lack of SNA in certain contexts, and literature reviews that focused only on the online context [14], [29]. To address these potential issues and identify areas for subsequent research, we underwent a scoping literature review of research in the engineering education context which included SNA. To guide our research toward the study purpose, we prepared the following Research Questions (RQs):

RQ1: What is the current breadth of SNA in the engineering education context?
RQ2: What areas of SNA in engineering education warrant systematic review(s)?

For this research brief, we present key publication, study context, and methodological trends in the data through an analysis of code frequency. Specifically, we will focus on findings related to RQ1 by identifying the number of records that included each code.

Methodology

A scoping review, as presented by Grant and Booth "provides a preliminary assessment of the potential size and scope of available research literature" [30, p. 95]. We selected this methodology, similar but distinct from a mapping review, as this study aims to identify the extent of existing literature, particularly the study design features, and to understand the breadth and depth of SNA applied in the engineering education context for performing subsequent systematic reviews. To ensure quality in our findings while recognizing the potential limitations of scoping reviews in oversimplifying prior work, we identified study records in the three standard steps of systematic reviews identified by PRISMA standards for literature search and appraisal [31]: identification, screening, and inclusion. Identification included an initial search, selection of validation papers to be included in the final review, and iterative meetings with a university librarian for an expert appraisal of the terms and process. Our final keyword search, applied in the ERIC, Education Source, and Scopus databases entry format was:

(Social network analysis OR "network analysis" OR social network OR network centrality) AND (classroom OR education OR students OR faculty) AND (engineering).

To ensure the findings were relevant to the engineering education research context and to meet the needs of the research team we prepared the following Inclusion Criteria (IC):

IC1: The study must be written in English.
IC2: The study must be a completed, primary source (no reviews or works in progress included).
IC3: The study must be published in 2022 or earlier.
IC4: The study must be peer-reviewed and refereed (i.e., conference papers and journals).
IC5: The study must apply SNA methods. Specifically, network analysis of social interactions.
IC6: The study sample must include engineering undergraduate/graduate students or educators.

Two coders applied these criteria, coding to consensus, to identify 59 final papers for analysis from the 3,197 search records. Figure 1 shows the entire scoping search and appraisal processes.

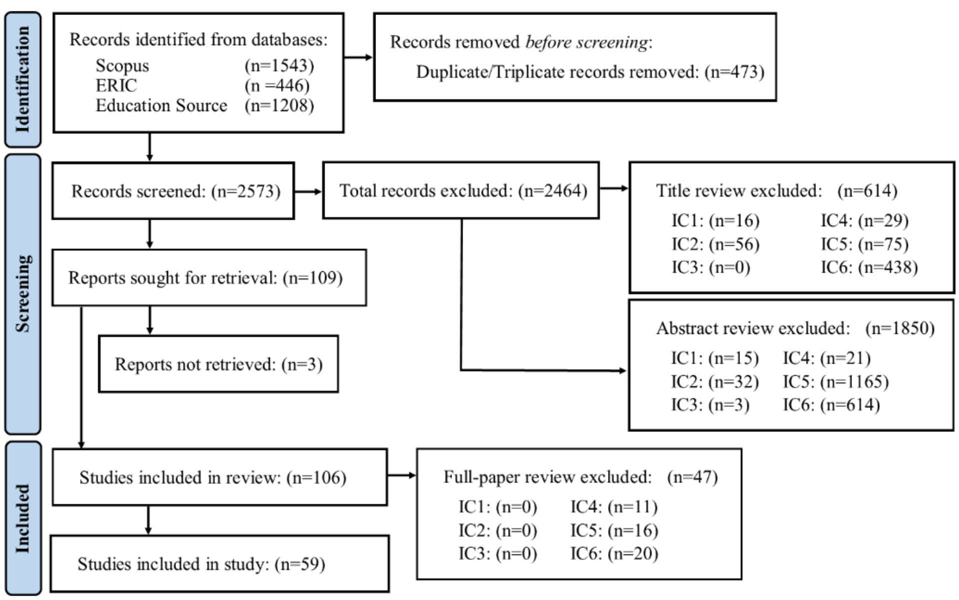

Figure 1. PRISMA diagram [31] of scoping literature review search and appraisal processes, extended from [32].

The full-paper review began with four coders each independently coding 3-5 papers according to the *a priori* categories described and developed in [32]. These categories included Paper Descriptors, Sample Descriptors, Methodology, SNA Data Collection, SNA Techniques, and Other Methodological Notes. The full research team met after coding the initial papers independently to discuss codes within these categories that should be added, omitted, adjusted, etc. This process was repeated twice and included identifying general study design areas of interest (e.g., methodology) and potential categorical values (e.g., mixed-methods or quantitative). After codes were finalized and written descriptions recorded for each code, the research team recorded relevant responses in a coding table for the remaining papers. This included deductively recording the *a priori* values for relevant categorical data, recording quantitative values as appropriate, and recording then memo-ing for those values that did not meet the *a priori* categorical or numeric codes [33]. Finally, the research team inductively coded those values that did not meet the requisites for the deductive codes and completed a final cycle of coding according to the full deductive and inductive codebook.

Results

To begin, we present the number of the 59 identified records that included SNA in the engineering education context by year of publication in Figure 2.

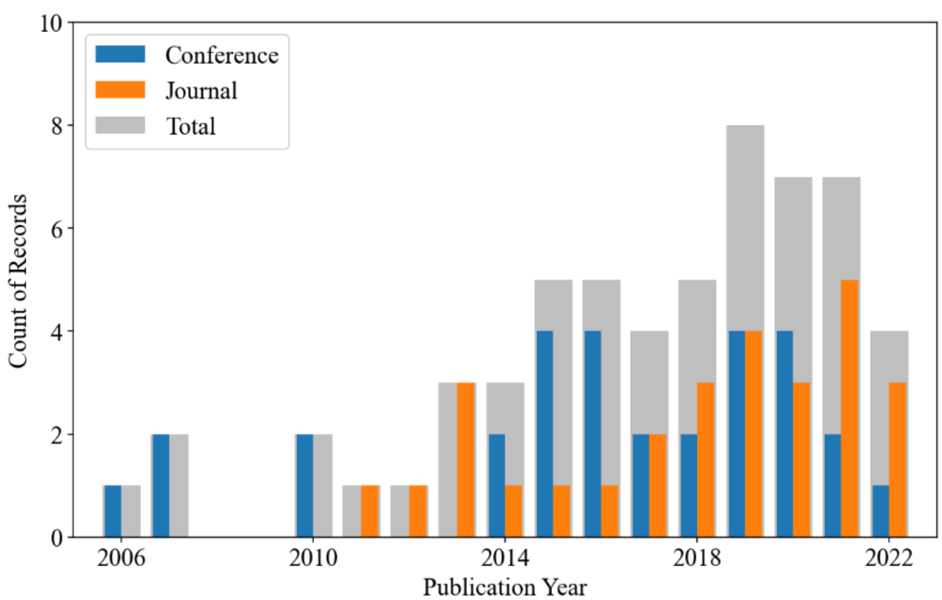

Figure 2. Review record counts vs. publication year.

From these data, we observe the emergence of SNA as an engineering education research method in 2006 and an increase in the use of SNA over the last two decades. Trends in these data also include a shift from most annual publications in conferences to most annual publications in journals within the last several years.

To identify and summarize record study context and methodological trends pertinent to our RQ, we deductively developed categories and inductively developed codes within the *a priori* categories. These codes relevant to the study design and context, and the count of records according to each category, are presented in Table 1.

Table 1. Study record counts vs. categories.

Primary Category	Codes	Count (n)
Sample Type	Students	48
	Faculty/Staff	10
	Other	2
Participants' Engineering Major	Unspecified or General	30
	Civil	4
	Software	3
	Mechanical	3
	Biomedical	2
	Computer	2
	Construction	2
	Aerospace	1
	Electrical	1
	Industrial	1
	Materials	1
	Systems	1
	Technology	1
Study Country	US	26
	China	6
	Australia	4
	Taiwan	2
	Chile	2
	Switzerland	2
	Finland	1
	India	1
	Portugal	1
	France	1
	Spain	1
	Ecuador	1
Participant Year (Students)	Year 1	19
	Year 2	17
	Year 3	13
	Year 4	17
	Graduate	9

Primary Category	Codes	Count (n)
Study Total Sample Size	< 50	17
	50 to 100	18
	101 to 250	14
	251 to 1000	5
	>1000	4
Sample Demographics Provided?	Yes	31
	No	28
Study Course Delivery Method	Face-to-Face	14
	Online	7
	Hybrid	7
Methodology	QUAN	35
	Mixed	24
Sampling in Time	Cross-Sectional	37
	Longitudinal	20
	Pre-Post	5
Network Data Collection Methods	Survey	35
	Auto	20
	Observation/Interview	8
Survey Type (*iff* survey)	Closed	21
	Open	15
Network Interaction Type	Online	20
	Face-to-Face	7
	Hybrid	7
	Not Specified	25
Longitudinal Sample Duration	< 1 Semester	3
	= 1 Semester	10
	> 1 Semester	5
Longitudinal Sampling Frequency (Weeks/ Sample)	Continuous	9
	3	2
	4	2
	5	2
	8	1
	52	1

***Note, record count sums across primary categories may give less than or greater than the 59 total review records due to code co-occurrence and/or lack of applicability.**

Overall, results demonstrate several areas of interest including the breadth of areas SNA has been applied, the relative focus of SNA in certain study contexts, and the specific focus of research applying SNA in certain data collection methods.

Discussion

Our analysis of these results identified several areas of particular interest in the relevant literature. To begin, Figure 2 demonstrates SNA as an engineering education method emerged concurrent with the development of engineering education as a discipline [34] adopting research methods from educational, learning, and social sciences [35]. Further elaborating this trend, the first identified record is a conference article and matches the expectation of methods being implemented in conference publications before maturation into journal publications several years later [36]. Qualitatively, this trend of periodic increases then decreases in conference publications, followed by time-delayed periodic increases then decreases in journal articles is exhibited throughout the data in Figure 2.

Clusters and Gaps in Study Contexts

Beyond the emergence and growth of SNA as a research method well-suited to the engineering education context, there exist several clusters of interest in the study samples. The first groups of interest we identified according to the three main study sample types: engineering students (81%: 48/59), engineering faculty and/or staff (17%: 10/59), and other (3%: 2/59). The "Other" category is of particular interest and is the result of two studies which analyzed communication networks within online, openly available engineering platforms that were not restricted to engineering students or faculty/staff. Outside of the other category, there is an emphasis in the research on undergraduate engineering students over research considering engineering faculty/staff. Further, within the records including student participants, only 19% (9/48) of those student-specific studies included graduates. Interestingly, however, the degree-path-completion specific categories do not have a relative emphasis, contrasting our expectations that there was a methodological focus on specific years. However, this finding may also be a result of the lack of specificity in some sample descriptions, and the overall general approach to describing samples in many of the studies.

To elaborate this point, only 53% of the records explicitly described the demographics of the study sample. This issue is of particular importance, as recent research suggests that student networks have a strong likelihood for *homophilic tendencies* (students selecting others to interact with who have similar traits [37]): along gender, race, ethnicity, sexuality, and other factors are particularly important in network formation and evolution [38]-[40]. Further, these tendencies can be particularly sensitive to multiple traits and intersectionality, highlighting the issues in network analysis which does not adequately sample participant demographics [27], [39], [41]. *Thus, the first key finding of this study is the relative lack of adequate demographic data collection and reporting, which is of particular importance in the engineering education network context.*

Gaps in Network Participant Bounds

Beyond trends in the study sample descriptors, we also identified several interesting trends within the study methods. The first of these trends is the focus of these studies on smaller samples. Specifically, 60% (35/59) of the studies used a sample of 100 or fewer participants, which are likely related to a single small to medium-sized course or a subsample from course(s). Further, only 15% (9/59) of the studies identified included a sample larger than 250 participants, suggesting samples larger than a single course. This indicates a likely focus of studies in engineering education applying SNA in a single course. While valuable, prior research has demonstrated that student networks, even peer-to-peer support networks for course-specific content, are not wholly captured by single-course enrollment [22], [42]. *Thus, the second key finding of this study is the relative lack of holistic networks/large samples used for SNA in engineering education.*

Gaps in Longitudinal Network Sampling

Continuing this line of reasoning, we considered the length of network studies, which has demonstrated importance in the efficacy of network interventions whose effects are only captured beyond a single semester in time [25], [40]. Recognizing this importance, we highlight that only 34% of the studies gathered longitudinal data, and only five studies (8%) extended beyond a single semester in sampling. Thus, the final key finding of this study is an elaboration of the second key finding: *there is a significant lack of engineering education research that considers holistic networks/networks beyond a single semester in time.*

Conclusion

This research brief summarizes study context and design findings from a larger scoping review of Social Network Analysis applied in the engineering education context. The purpose of this review is to identify the current breadth of SNA applied in the engineering education context and identify areas for subsequent research. Among the selected findings of this review, this brief demonstrates the emergence and persistence of SNA in the existing body of engineering education literature as a method to quantify and analyze interpersonal relationships between engineering students, faculty, staff, and interested independent learners.

Despite the breadth of applications, we also identified several key areas for SNA to provide future benefits including a) the need for future SNA studies to consider and thoroughly report participant demographic data, b) the importance of extending student network data beyond a single course in participants, and c) the importance of extending network data collection beyond a single semester in time. While we believe these findings independently add value to the existing body of literature by summarizing the breadth and depth of existing literature and providing several areas to emphasize for future research, our later presentation of this work will extend these findings. Continued plans for this study include analyzing the coincidence of categorical codes (e.g., identifying and considering the number of papers that were longitudinal and had a sample > 250 participants,) and quantitative clustering of existing papers through bipartite network projection and subsequent clustering [18], [43], [44]. Finally, we will develop recommendations for efficient strategies to study networks that meet the existing gaps, recognizing the increased resource cost incurred by extending network sample bounds.

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Note, that all review articles are preceded by an asterisk (*).

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