Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #46266

BOARD # 230: CATENA: An IUSE:EDU project to evaluate STEM education capacity through social network analysis

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Varun Kathpalia, born and raised in northern part of India, joined EETI as a PhD student in the Spring of 2024. He completed his undergraduate degree in Mechanical Engineering from Chitkara Institute of Engineering and Technology (Punjab Technical University, India) and master's degree in Mechanical Engineering, specializing in Manufacturing & Materials Science Engineering, from the Indian Institute of Technology, Kanpur, India. He has over 4 years of corporate experience with companies such as Hindustan Coca-Cola Beverages Pvt. Ltd. and Saint-Gobain India Pvt. Ltd. (Research & Development). His interest in areas such as improvement in instructional techniques, faculty perspectives and teaching methodologies, drove him towards the domain of Engineering Education. Specifically, the question of how engineering education can be made more effective and engaging fascinated and motivated him to pursue research in this domain.

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CATENA: An IUSE:EDU project to evaluate STEM education capacity through social network analysis

Our IUSE:EDU Project (Institutional & Community Transformation track) seeks to create and pilot a quantitative social network analysis (SNA) survey instrument that will allow STEM higher education leaders to assess STEM education capacity in their local institutions. This instrument will be based on in-depth, qualitative data to determine how STEM education capacity manifests in STEM higher education settings. STEM education capacity refers to the ability and empowerment of system actors (faculty, staff, graduate student instructors, etc.) to adapt to changing needs and collectively achieve shared objectives that contribute to STEM student success [1-4]. Capacity is hard to measure, as it is only readily observable when mobilized to address a major change initiative or crisis (e.g., when universities pivoted to online learning during COVID-19.) Nonetheless, understanding STEM education capacity is essential to understanding STEM education change from a complex systems perspective. Complex systems theory, which pushes back on the notion that institutional change can be envisioned as a chain of cause and effect between a single initiative and a lasting result [5, 6]. Rather, institutional change requires attention to systemic conditions for change, such that all relevant system actors are willing and agile enough to collectively move in a productive direction—a feat that requires significant, intentional, and continuous preparation [1, 4, 6].

We operationalize STEM education capacity using the Five Capabilities (5C) Model [2], which characterizes capacity building efforts as increasing the capability of system actors to engage in five interrelated activities (detailed in Table 1.) We posit that three of the capabilities (commit and engage; relate and attract support; balance diversity with coherence) require attending to relationships within higher education systems (e.g., partnerships, collaborations, and professional interactions.) The other two capabilities (carry out tasks and produce results; adapt and self-renew) also rely heavily on relationships, as our initial results attest. Accordingly, we propose that STEM education capacity can be assessed by using social network analysis to understand the relationships and interactions among system actors.

Table 1: Five Capabilities Model of Capacity

Dimension of capacity	**Examples of activities aligned with capability**
Capability to commit and engage	Mobilize resources; create autonomy for independent action; motivate the skeptical or unwilling; collectively exercise other capabilities
Capability to carry out tasks and produce results	Perform at acceptable levels; generate substantive results; sustain productivity over time; add value to the organization
Capability to relate and attract support	Establish partnerships and alliances, and leverage resulting resources; build legitimacy in the eyes of stakeholders; deal effectively with organizational politics and power structures
Capability to adapt and self-renew	Adapt plans and action by monitoring progress and outcomes; proactively anticipate and respond to new challenges; learn by doing; cope with change; develop resiliency
Capability to balance diversity with coherence	Develop shared vision across multiple time horizons; balance control and consistency with flexibility; integrate and harmonize plans across a diverse set of actors; cope with cycles of stability and change

When complete, this project's work will yield the following overarching outcomes:

1. A **fundamental understanding of STEM education capacity** as it manifests via interactions and network features in STEM education centers.
2. The **CATENA Instrument**: A novel survey instrument for SNA to capture these facets of capacity in interactions between system actors.

3. A **well-documented SNA data collection and analysis process** that will allow STEM higher education leaders to assess STEM education capacity at their institutions.

This paper overviews the overall project design and then focuses on the results of our first year of work.

Overall Project Design

Our project follows a three-phase model, and each phase addresses a different research question (Table 2). Phase 1 (the current phase) involves 15 interviews to ascertain what kinds of relationships and interactions participants consider important to building their capacity to support student success. Phase 2 will use these results to develop a preliminary SNA instrument (the "CATENA Instrument") to quantify relationships of interest, and will refine the CATENA Instrument through cognitive interviews. Finally, Phase 3 will deploy the instrument across UGA's College of Engineering.

Table 2: Overview of research plan and outcomes

Phase & Research Question	Summary of Research Methods	Expected Research Outcomes
Phase 1: What types of interactions between faculty, staff, and graduate students advance STEM education capacity along each of the capabilities defined by the Five Capabilities Model?	• Qualitative, Exploratory • 15 participants • 30-60 minute interviews based on the Five Capabilities Model	• A **list of salient interaction patterns** that help cultivate local STEM education capacity (used to inform Phase 2)
Phase 2: How can each of the types of interactions observed through answering RQ1 be measured quantitatively through the design of the CATENA instrument?	• Participatory, Design-Based • 15 participants • Translation of Phase 1 results as basis for CATENA instrument design • Cognitive interviews with participants to iteratively refine instrument's design	• The **CATENA Instrument** to quantitatively capture local interactions to create social networks (used as the data collection instrument for Phase 3) • Documented **face validity** evidence for the CATENA instrument
Phase 3: What network topologies emerge as significant for evaluating STEM education capacity in the networks created from piloting the CATENA Instrument created in answering RQ2?	• Quantitative, Exploratory • Minimum 130 engineering faculty, staff, & grad student participants • CATENA instrument deployment • Creation of sociograms and analysis of network topologies • Compilation of validity and reliability evidence for CATENA instrument	• Documented **validity and reliability** evidence for the CATENA instrument • A **well-documented process** for collecting and analyzing data using the CATENA Instrument. • **Recommendations** for STEM education centers aiming to build local education capacity

Year 1 Research Methods

We have completed two batches of interviews (five interviews each) for the project's first phase. Interviewees comprised UGA faculty across engineering disciplines, academic rank (including tenure-track and instructional-track ranks), and amount of time at UGA. Interviews were semi-structured and lasted 60 minutes. Each interview was audio-recorded and transcribed for analysis.

The interview protocol changed from the first to the second batch. The first batch of interviews used an interview protocol that asked questions about critical incidents where faculty sought support from others aligned with each of the five capabilities. For example, for the capability to carry out tasks and produce results, we asked, "Tell me about a time when an idea you tried in the classroom turned out really well. What kinds of support or feedback did you receive that contributed to that success?" During data collection, we noted that participants found it difficult to think of appropriate scenarios, even when we provided the questions in advance. When we analyzed the interview transcripts, we realized that it was because our questions assumed that most academic social interactions were transactional (i.e., that faculty approached one another primarily because they wanted something out of the interaction.) Instead, our participants reported that many of their most meaningful interactions emerged from casual hallway conversations. In response to this observation, we adjusted the interview protocol to ask participants to freely identify recent meaningful conversations with colleagues, and use probing to expand their network of colleagues and meaningful interactions from there. This interviewing technique produced more interesting responses that allow us to better address our research questions.

Analyzing the first batch of interviews required similar flexibility. Our original plan to map interactions to the 5C Model using a priori codes did not go well, as participants often struggled to answer the 5C-mapped questions directly. Instead, we focused on using open coding to identify the content and nature of the interactions participants did describe, which ultimately allowed us to revise our interview protocol. For a detailed analysis of our findings related to the first batch of interviews, see [separate ASEE 2025 paper]. We are currently in the process of analyzing the second batch of interviews; we are using a mix of open and a priori codes to identify patterns of relationships participants describe (e.g., mentorship, friendship, sharing of resources and ideas, etc.) and align these relationships to the capabilities with which they most closely align in the 5C Model.

Year 1 Results

The first batch of interviews yielded critical insights into the nature of faculty relationships. These insights allowed us to better address our research questions in follow-up interviews and highlight important insights for the design of STEM higher education spaces.

The first insight is that **faculty relationships are rarely transactional**. We assumed in our first interview protocol that faculty primarily approached one another with a goal in mind that they wanted to achieve from the conversation. However, we were able to achieve more meaningful responses when we deviated from the protocol and instead asked participants about recent meaningful interactions with colleagues. We found that most meaningful conversations between faculty came about not because of one person seeking out another, but rather emerged from informal "hallway conversations" where participants ran into each other and stopped to catch up. One participant described hallway conversations happening as they ran into colleagues while preparing for class: "Lecturers are going have a conversation. […] Like, if you are in a copy room and you're copying [and you see a colleague], you have a conversation, and you are being asked or asking something." Participants described that more frequent hallway conversations led to deeper relationships and a greater frequency of collaboration and meaningful discussion. Returning to the previous example, if a faculty member was struggling to teach a large class, it is rare they would seek out someone with the expertise to address that issue. Rather, they would express their frustrations during a hallway conversation, and that conversation would transform into a discussion where they shared ideas with a colleague on how to address the issue.

The second, related insight is that **faculty members' physical locations relative to their peers played a major role in shaping participants' social networks**. Because hallway conversations were the starting point of many meaningful interactions, faculty formed the strongest relationships (and interacted most) with the colleagues they saw most frequently. When asked about who he tends to go to when he wants to talk about teaching and learning, for example, one faculty member responded: "It's been [the faculty that are around] on my little half of [my building] […] There's faculty all the way on the other side of [my building] that I haven't really touched base." This phenomenon was especially pronounced with faculty who had been at UGA for a long time and had moved offices from UGA Engineering's central building to one of its new satellite research buildings. These faculty described a nostalgia for running into office neighbors and having interesting conversations about teaching and learning. However, because the satellite research buildings do not host classes, they now rarely discuss teaching with office neighbors, who return to their offices to focus on research activities. These faculty described a shrinking of their teaching-and-learning-focused social networks over time.

Implications & Next Steps

Our results emphasize that creating time and space for hallway conversations is essential for growing and maintaining STEM higher education social networks. For STEM education leaders, the results suggest that **creating shared spaces for both research and teaching** (e.g., avoiding satellite buildings for research only) allows for more hallway conversations about teaching and learning. Further, mixing faculty roles (i.e., **instructional and research faculty sharing a space**) ensures that hallway conversations are varied in their topics, allowing faculty to leverage their social networks for professional growth in multiple areas, including teaching and learning.

We intend to continue exploring themes like this that emerge as participants talk about patterns in their social networks. However, our immediate next step is to analyze our second batch of interviews in a way that allows us to return to our original research question. We will focus on identifying the kinds of roles different people play in participants' social networks around teaching and learning. We will also identify how these different roles relate to the 5C Model of Capacity. Finally, we will conduct a third batch of interviews to bring in perspectives not yet represented in our data (e.g., staff and graduate students that contribute to student success.) Insights from these interviews will allow us to draft a SNA instrument that enables the project's remaining two phases of work.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2315532. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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